EVALUATION OF THE FLEET NUMERICAL WEATHER CENTRAL OPERATIONAL PRIMITIVE-EQUATION MODEL IN FORECASTING EXTRATROPICAL CYCLOGENESIS

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THESIS

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March 1973

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY

from the

NAVAL POSTGRADUATE SCHOOL
March 1973

ABSTRACT

This paper describes an attempt to find systematic errors in the 12, 24 and 36-hour sea-level pressure forecasts of extratropical cyclogenesis produced by the operational five-layer primitive-equation model of the Fleet Numerical Weather Central, Monterey, California. The sample of cases studied contained 488 cases for the 12-hour, 484 cases for the 24-hour, and 446 cases for the 36-hour verifying times. The sample was extracted from the storm season spanning the period October 1971 through March 1972. Several systematic errors exist. They are: 1) an underforecast of the deepening rate in a majority of cases; 2) a tendency to greatly underforecast the deepening rate in the 12-hour prognoses and then to underforecast to a lesser degree or overforecast the subsequent 12-hour changes; 3); a tendency to forecast the track to the right of the actual track; and 4) a tendency to forecast the 36-hour position to the south and west of actual position. When compared to the National Meteorological Center's six-layer primitive-equation model, Fleet Numerical Weather Central's model showed comparable or superior performance.

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ACKNOWLEDGEMENTS

The author wishes to thank Professor Tracton, faculty advisor, for his valuable assistance and guidance throughout this study.

Appreciation is also extended to Mr. Clarke of Fleet Numerical Weather Central, Monterey, California, for his description of the primitive-equation model and changes made to it, to Mr. Zuver also of FNWC for his assistance in obtaining data, and to Mr. Brody of the Environmental Prediction Research Facility, Monterey, California, for the use of data and facilities.

My deepest appreciation goes to my wife, Wendy, who not only put up with my bad humor when things were not going smoothly, but also cheerfully gave up the pleasures of her evenings and weekends to allow completion of this study.

I. INTRODUCTION AND BACKGROUND

Since September 1970, the United States Fleet Numerical Weather Central (FNWC), Monterey, California, has fulfilled the responsibility of providing operational numerical meteorological forecasts by means of a five-layer, primitive-equation (PE), atmospheric prediction model initiated by a M.S. thesis by P. G. Kesel under the direction of Professors G. J. Haltiner and R. T. Williams of the Naval Postgraduate School. Further development was continued by P. G. Kesel and F. J. Winninghoff at FNWC (Kesel and Winninghoff, 1972). From the time of its operational implementation, the PE model has been subject to continuing study, research, development and modification by Kesel, Winninghoff, Clarke and others of FNWC. Unfortunately, documentation of these changes has not been officially published and is available only by personal conversation with those involved; however, it has been ascertained that major changes in the radiation, precipitation, and diffusion aspects of the model, along with various minor and cosmetic changes have been made in the continuing quest to output the best possible product.

In mid-latitudes, significant weather is almost invariably associated with cyclonic systems. It is therefore possible, to a large extent, to infer weather patterns from frontal-cyclone models. While it must be recognized that a "perfect" forecast is virtually impossible due to

mesoscale weather phenomenon, the ability to more precisely forecast local weather is in direct relationship to the timely knowledge of the development and movement of the synoptic scale patterns.

Studies by Fawcett (1969), Leary (1971) and Tracton (1972) have demonstrated that systematic errors in forecasting cyclogenesis exist in the National Meteorological Center (NMC) six-layer PE forecast model (Shuman and Hovermale, 1968). Until now, however, a detailed study has not been made to determine the existence and nature of systematic errors in the FNWC-PE forecasts of extratropical cyclogenesis. Therefore, the user at the local level has had to rely upon his own intuition, experience, and assumptions made from NMC-PE verifications.

II. OBJECTIVE OF THE STUDY

The objective of this study is to document systematic errors, if any, in FNWC-PE 12-, 24- and 36-hour forecasts of extratropical cyclogenesis.

III. VERIFICATION PROCEDURES

At the outset of this study the fact was recognized that, in order to produce the most meaningful results possible in the limited time available, it would be necessary to reconcile such factors as availability of data, timeliness of data with respect to major changes in the FNWC-PE model, sample size, and approach utilized in analysis of the data. With this in mind, the following data limitations and methods of analysis were established.

A. DATA

1. Data Sources

Data was obtained from:

(1) NMC hand-analyzed sea-level pressure charts at six-hour intervals. (Courtesy of Environmental Prediction Research Facility, Monterey, California).

(2) FNWC computer analyzed sea-level pressure charts and 500-mb charts at 12-hour intervals.

(3) FNWC-PE 12-, 24- and 36-hour sea-level and 500-mb prognoses. (FNWC products courtesy of FNWC Climatology Section)

2. Geographical Limits

Geographical limits were established from 20N to 75N latitude and from 105E east to 40E longitude. This area was then segmented into four smaller geographical areas to

facilitate ease in data collection and evaluation of model performance (Figure 1).

a. Area 1

Area 1 (105E-180) includes the eastern continent of Asia, off-lying islands, and the western Pacific.

b. Area 2

Area 2 (180-110W) includes the eastern Pacific and the western portion of North America.

c. Area 3

Area 3 (110W-60W) includes the majority of North America east of the Rocky Mountains and the Western Atlantic.

d. Area 4

Area 4 (60W-40E) includes the central and eastern Atlantic, Greenland, Europe and a small portion of northwest Africa.

3. <u>Time</u>

A sample of 6 months from October 1971 through March 1972 was chosen. This period included one storm season and was free from any major changes in the FNWC-PE model.

4. <u>Cyclone Selection</u>

In order to screen out systems without significant development, only those cyclones with a minimum deepening of central pressure of 4 mb in 6 hours, for at least one 6-hour period, or 6 mb in 12 hours, for at least one 12-hour period, were considered. Those storms which were analyzed in sparse data areas without reports confirming or implying

the analyzed central pressure were eliminated from consideration in the attempt to keep the NMC data on an observational basis, thereby reducing the "human element" bias.

5. Cyclone Types

For the purposes of this study, systems were categorized into the following cyclone types based on their stage of development.

a. Frontal Wave

Frontal waves are those cyclones nascent on a wave. At this stage of development, closed contours may or may not be present.

b. Wave Cyclone

Wave cyclones are those with closed contours wherein the warm and cold fronts are just beginning to convolute. This stage continues until the first signs of occlusion appear.

c. Occluding Cyclone

Occluding cyclones are those in which the cold front has overtaken the warm front. This stage continues until full occlusion occurs.

d. Occluded Cyclone

The occluded cyclone is one which no longer has any frontal structure (i.e. cold low).

B. APPROACH

1. Sea-level Pressure

The NMC hand-analyzed sea-level pressure charts were surveyed for cyclones meeting the aforestated criteria. Such

systems were identified by time, date, central pressure and cyclone type for 0000, 0600, 1200, and 1800 GMT. For 0000 and 1200 GMT, latitude and longitude were also recorded.

The FNWC analysis and the 12, 24 and 36-hour PE sea-level prognoses were matched by system with the NMC data. For example, a qualifying cyclone which began to deepen at 0000 GMT and continued to show significant deepening through 1200 GMT two days later, a period of 60 hours, would yield 3 comparisons of the 12-, 24- and 36-hour FNWC-PE prognoses and actual systems, the first spanning the period from 0000 GMT through 1200 GMT the following day, the second from 1200 GMT the first day through 0000 GMT the third day, and the third from 0000 GMT the second day through 1200 GMT the third day (Figure 2). Comparisons were terminated when either filling commenced or significant deepening stopped. In those cases where no closed isobars were analyzed or forecast, the central pressure was taken as the pressure along the trough axis from which the cyclone developed. The stages of development could not be determined from the FNWC charts; therefore, forecast stages of development were considered to be the same as those at the NMC verifying time.

After the actual and forecast systems were mated, the change in central pressure of each was determined for both 12-hourly increments (i.e., 0-12, 12-24, and 24-36 hours) and by verifying time increments (i.e., 0-12, 0-24, and 0-36 hours) (Figure 3). The forecast changes in central pressure were reckoned from the machine analyzed central

pressures from which the forecasts were generated. This was done in recognition of the fact that machine and hand analyses differ, and that the PE forecasts are dependent on the machine analyses.

The mated changes in central pressure were then reduced to errors in the FNWC-PE forecasts of deepening rate by subtracting the observed from the forecast values. The resulting differences indicate, if positive, an underforecast (i.e. not enough deepening); if negative, an overforecast; and if zero, agreement between forecast and actual change. Those cases where a cyclone was analyzed on the NMC chart but not generated by the PE model (i.e. no minimum in the pressure field) were defined as "not forecast".

2. Position

Position errors were calculated for only the 36-hour prognoses in terms of the difference between the observed and forecast latitude and longitude coordinates of corresponding systems for only the 36-hour prognoses. The stage of development was not considered. The resulting errors were plotted on scatter diagrams (Figures 16 through 19) with the actual position being the origin of the grid.

3. Track

Due to time limitations, all systems could not be inspected for track errors. Consequently, only those storms with an actual deepening rate of at least 18 mb over a 36-hour period beginning at either 0000 or 1200 GMT were

considered. A further limitation was that the initial, 12-, 24- and 36-hour positions of both NMC and FNWC systems be firmly established; thus, systems with nebulous positions (i.e. without closed contours, those not forecast, and those for which data were unavailable due to missing charts) were removed from consideration. The final sample consisted of 121 storms.

Track error for the above mentioned sample was established by comparing the mated NMC and FNWC initial, 12-, 24- and 36-hour positions plotted on a single chart. Since the NMC and FNWC analyses of initial position were not necessarily coincident, the plotted tracks were adjusted until the initial positions were coincident. The performance of the model in forecasting storm track was then evaluated in terms of whether the forecast position was to the left or right of the observed track.

4. 500-mb Heights

Verification of 500-mb prognoses was restricted to evaluating 36-hour forecasts of trough depth, motion, and sea-level to 500-mb slope for a limited number (40) of storms comprising the total sample.

IV. RESULTS

A. EVALUATION OF 12-, 24- and 36-HOUR PROGNOSES OVER THE TOTAL AREA

Table 1 compares the performance of the 12-, 24- and 36-hour prognoses over the total area without regard to the stages of development. The summary section of Table 1 demonstrates a tendency of the FNWC-PE model to underforecast the deepening of cyclonic systems with underforecasts observed in 64.8 percent of the cases at 12 hours, 65.0 percent at 24 hours and 69.0 percent at 36 hours. The tendency to underforecast development is further shown by Table 2 which lists the average forecast error. At 12 hours the average forecast error was an underforecast of 3.4 mb, at 24 hours an underforecast of 4.8 mb, and at 36 hours an underforecast of 5.3 mb. It should be noted, however, that the magnitude of the average error, while it did increase, did not increase linearly. The rate of increase was from 0 to 3.4 mb during the first 12 hours, dropped to 1.4 mb during the 12 to 24-hour period, and was reduced even further to 0.5 mb during the 12-hour period between 24 and 36 hours. This reduction in the rate of increase of the average error implies that the magnitude in the underforecast of the 12-hour changes of central pressure generated by the PE model was less during the 12-24-hour period than during the initial period and was further reduced between 24 and 36 hours.

Further analysis of Table 1 reveals that the underforecast to overforecast ratio fell from 2.8:1 in the 12- and 24-hour forecasts to 2.0:1 at 36 hours. This indicates that although the tendency was to underforecast the 12-hour changes between the 0-12 and 12-24-hour forecasts, the PE model at times overforecast the 12-hour change between 24 and 36 hours to the extent that the net change over 36 hours resulted in an overforecast vice an underforecast.

Table 1 also shows that the number of storms accurately forecast (i.e. within $\pm$ 4 mb) fell from 46.9 percent at 12 hours to 31.2 percent at 36 hours, indicating that the overall reliability of the PE model decreased with time.

Figures 4 through 15 present a further comparison of the forecast and observed deepening rates. Observed and forecast changes of central pressure are plotted along the abscissa and ordinate, respectively. Points lying above the "FCST=OBS" line represent overforecasts, and points lying on the line represent perfect forecasts. The vertical distance between a point and the line indicates the magnitude of the error in deepening rate. The nature of these scatter diagrams did not lend itself to a plot of the total area due to the number of overlapping points; however, viewed collectively, Figures 4 through 15 illustrate again the overall tendency of the model to generally underforecast development. Also it can be seen that the magnitude of the error tends to increase with an increase in the observed deepening rate. Tersely stated, the largest errors occur

with storms that intensify the most. The fact must not be overlooked, however, that on occasion the model does accurately forecast even the most intense storms.

Tables 4 through 6 illustrate the performance of the 12-, 24- and 36-hour prognoses with respect to the stage of development (i.e. storm type). These tables show that the model forecast 92.9 percent of all frontal waves. With respect to forecast periods, the model did not forecast 7.1 percent of the frontal waves at 12 hours, while all of the frontal waves were forecast at 24 hours. Of the three frontal waves that were observed at 36 hours, two were forecast. Wave cyclones were not forecast 9.2 percent of the time by the 12-hour prognoses, 1.3 percent were not forecast by the 24-hour forecast and all waves were forecast at 36 hours. The occluding stage, which comprised the majority of the cases in all forecast periods, was not forecast 4.7 percent of the time at 12 hours, 1.8 percent at 24 hours and 4.9 percent at 36 hours. All occluded storms were forecast at 12 and 24 hours and only 1.4 percent were not forecast at 36 hours.

With regard to forecast period, the stages of development with the greatest and least number of cases underforecast were, respectively, the occluding storms, 70.6 percent. and the occluded storms, 47.1 percent, at 12 hours; the occluded storms, 75.9 percent, and the frontal waves, 53.9 percent, at 24 hours; and the occluding storms, 70.7 percent, and the occluded storms, 55.9 percent, at 36 hours.

Table 2 indicates that the best performance with respect to average error was achieved in forecasting frontal waves with average underforecasts of 0.3 mb at 12 hours and 2.0 mb at 36 hours (based on three storms), and an average overforecast of 0.3 mb at 24 hours. The poorest results were realized for the occluding stage with 12-, 24- and 36-hour average underforecasts of 5.1 mb, 6.4 mb, and 7.5 mb, respectively. This is consistent with the fact that the greatest intensification is usually experienced in the occluding stage and that, as discussed earlier, the largest errors occur with the most intense storms.

B. EVALUATION OF 12-, 24- AND 36-HOUR PROGNOSES BY CYCLOGENESIS AREA

Tables 7 through 18 show the performance of the FNWC-PE 12-, 24- and 36-hour prognoses by cyclogenesis area. Tables 7 through 9 deal with the model's performance in Area 1. The 12- and 24-hour forecasts in Area 1 showed performance superior to that for the total area with 54.2 and 44.5 percent of the cases forecast accurately. In addition, the model was superior in the 24-hour forecasts of occluded systems. Only 1 of 182 such cases was not forecast. The 36-hour forecast prognosticated accurately only 26.6 percent of the time.

Tables 10 through 12 show the model's performance in Area 2 to be generally above that for the total area, especially in the 24- and 36-hour forecasts where 45.7 and 43.3

[illegible]

percent of the cases, respectively, were forecast accurately. Table 10 shows that the 12-hour forecasts did not forecast 11.7 percent of the waves and 8.7 percent of the occluding cyclones. An overforecast in 52.9 percent of the cases was observed for the waves in this area. This overforecast and an overforecast of 50.0 percent of the frontal waves at 12 hours in Area 3 (Table 13), were the only two occurrences of of this nature, with these two exceptions, a majority of the cases were underforecast for all areas, all time periods, and all stages of development.

As shown by Table 2, the PF model achieved its best performance in Area 2, with respect to average forecast error, with average underforecasts of 3.0 mb at 12 hours, 3.3 mb at 24 hours, and 1.1 mb at 36 hours.

Tables 13 through 15 show the performance of the model in Area 3. As indicated by Table 13, 47.6 percent of the cases were forecast accurately at 12 hours; however, the 24- and 36-hour performances fell short of those for the total area with 27.1 and 26.4 percent of the cases, respectively, being forecast accurately. The occluding and occluded stages showed significantly larger percentages of cases underforecast than those of the total area for all forecast periods.

As shown by Table 2, the average forecast errors for Area 3 were underforecasts of 5.4 mb at 12 hours, 7.0 mb at 24 hours, and 6.7 mb at 36 hours. These were the largest errors observed in any area.

Tables 10 through 12 show the performance of the model in Area 4. As shown by Table 16, all of the frontal waves not forecast by the PE model at 12 hours occurred in this area. Table 17 indicates that only 2.6 percent of the cases were forecast accurately in this area.

C. TRACK

As previously described, 121 cases were tested for track error with the following results:

	12-HOUR	24-HOUR	36-HOUR
Left of actual track	24(19.9)	30(24.8)	32(26.4)
Along actual track	15(12.4)	10(08.2)	13(10.8)
Right of actual track	82(67.7)	81(67.0)	76(62.7)

(Parentheses indicate percent; numbers indicate cases observed.)

It should be noted that the decrease in percentage between those storms right of actual track between 24 and 36 hours indicates that some storms crossed back to the left of the actual track between 24 and 36 hours.

D. POSITION

Only the 36-hour position error was investigated and the results are shown in Figures 16 through 19. While every conceivable position error was observed, the majority of the forecast positions were to the southwest of the observed positions. As shown by Table 3, the average 36-hour position error for the total area was 1.5°S and 2.4°W. It should be noted that this is the forecast position error. In applying the values from Table 3 to the forecast in order

to improve its accuracy, the forecast position should be corrected to the north and east. The forecast error being to the southwest, since most systems move northeast, indicates the model is slow in forecasting movement.

E. 500-mb HEIGHTS

The limited verification of 500-mb forecasts revealed a general tendency for the 36-hour prognoses to underforecast the depth of troughs, to be slow in the movement of troughs eastward, and to forecast too great a slope between the sea-level and 500-mb systems. Similar behavior was also observed in the NMC-PE model 36-hour forecasts of 500-mb heights (Tracton, 1973; Fawcett, 1969).

It should be noted that the intent in this study was not a systematic verification of FNWC-PE 500-mb prognoses, but rather to point out that there appears to be systematic errors in the FNWC-PE prognoses similar to those documented for the NMC-PE model.

V. EXAMPLE OF FORECAST ERRORS

The sea-level pressure charts appearing in Figures 20 through 23 present a comparison of the FNWC initial analysis for 0000 GMT 19 February 1972 and the 12-, 24- and 36-hour PE model forecasts generated therefrom with the corresponding NMC initial and verifying analyses. This system represents one 36-hour segment of major cyclonic development along the eastern coast of the United States (Area 3). The following is a tabular summary of the observed and forecast values of central pressure (CP) and the forecast error in deepening rate.

OBSERVED AND FORECAST VALUES OF CENTRAL PRESSURE

DTG	OBSERVED CP	CHANGE	FORECAST CP	CHANGE	FNWC ANALYZED CP
00 19FEB72	1002 mb				999 mb
12 19FEB72	982 mb	-20 mb	990 mb	-9 mb	
00 20FEB72	976 mb	-6 mb	975 mb	-15 mb	
12 20FEB72	974 mb	-2 mb	979 mb	+4 mb	

FORECAST ERROR IN DEEPENING RATE

DTG	12-HOUR INCREMENTS	VERIFYING TIME INCREMENTS
00 19FEB72	0	0
12 19FEB72	+11 mb	+11 mb
00 20FEB72	-9 mb	+2 mb
12 20FEB72	+6 mb	+8 mb

(FNWC central pressures are recorded to tenths of millibars. Central pressures shown here have been rounded to the nearest whole number.)

It can be seen that the FNWC computer-analyzed central pressure was 3 mb lower than that analyzed by NMC. Since the data utilized in the FNWC analysis was not plotted, the basis for the lower CP cannot be explained; however, Figure 20 shows adequate reports to establish the NMC analyzed value. At 1200 GMT 19 February 1972, 12 hours after initial time, the FNWC forecast a change in CP that was less than the observed change (i.e. an underforecast of 11 mb). During the next 12 hours, the actual central pressure decreased 6 mb while the PE model forecast a deepening of 15 mb. This established an overforecast of 9 mb for the second 12-hour period and a 24-hour net underforecast of 2 mb. During the final 12-hour period, the observed CP decreased further by 2 mb, but the PE forecast an increase of 4 mb, thereby producing an underforecast of 4 mb for the twelve-hour period and a net 36-hour underforecast of 8 mb. It should be noted that although the 36-hour error in deepening rate was 8 mb, the 36-hour forecast in central pressure was only 5 mb higher than the observed central pressure. This was due to the different initial analyses.

Figure 24 shows the earlier described adjustment made to the forecast track to enable track comparison. It can be seen from Figure 23 that the forecast system moved to the right of the actual track for the first 12 hours. After that it crossed over to the left of the actual track between 12 and 24 hours and remained there between 24 and 36 hours.

The 36-hour position of the forecast storm was $2^{o}S$ and $6^{o}W$ of the observed position.

Figure 25 compares the analyzed 500-mb heights and sea-level cyclone position for 1200 GMT 20 February 1972 with the 36-hour forecast 500-mb heights and sea-level cyclone position verifying at this time. It can be seen that the forecast 500-mb height is not deep enough, the forecast is slow in trough translation, and the slope between the forecast sea-level system and 500-mb trough is greater than that observed.

It must be realized that few storms demonstrate all of the "average" errors discussed in this thesis; however, most storms will exhibit some of the "average" errors. This example is no exception.

VI. SUMMARY AND CONCLUSIONS

A. DISCUSSION OF RESULTS

In terms of deepening of the central pressure, the FNWC-PE model does, by-and-large, forecast cyclogenesis to occur although the magnitude of the forecast development is generally less that that observed. The fact that some cases of later stages of development were not forecast is indicative that the model frequently fails to properly recognize skagerraking (i.e. secondary cyclogenesis at the apex of the warm sector). Failure, in some cases, to forecast the earlier stages of development (all in Area 4) is likely due to the failure of the model to properly include convective processes (Tracton, 1972). The tendency to underforecast all stages of development in all three forecast periods (0-12, 0-24, 0-36 hours) effected a decrease in the number of cases forecast accurately (i.e. within $\pm$ 4 mb) with forecast interval. The rate of increase in the average forecast error was not linear. This indicated that the underforecast of the 12-hour changes (0-12, 12-24, 24-36 hours) in central pressure decreased with forecast interval.

With respect to the average error in forecast deepening, Areas 2 and 4 showed the best results with Area 1 following closely behind. The poorest performance was observed in Area 3, which also had the lowest number of cases forecast accurately. It should be noted that Areas 1 and 3 are

regions geographically favored for the development of major cyclonic systems (i.e. storms which deepen the most) and as was discussed in the Results section, the error in forecast deepening rate increased with the magnitude of actual deepening.

The FNWC-PE model tended to forecast the cyclone track to the right of the actual track and the 36-hour forecast position was generally south and west of the observed position.

B. COMPARISON OF FNWC AND NMC-PE MODEL PERFORMANCE

The approach used by Leary (1971) in investigating the performance of the NMC-PE model was somewhat different from this study in terms of both the storm sample and the techniques used in gathering and analyzing data; therefore, absolute comparisons cannot be made. Nevertheless, it is clear that both models underforecast development; and, while the FNWC and NMC-PE 36-hour forecasts compare favorably in Area 3, the FNWC-PE model is far superior in Area 2. The tendency for the 36-hour forecast track to lie to the right of that observed, and the 36-hour forecast position errors also compare favorably.

The comparability of the PE models in Area 3 was further verified by a comparison of each model's performance for a limited sample of storms used in this study (Tracton, 1973). Also, when compared to the NMC Limited Area Fine Mesh (LFM)

model (Howcraft, 1971), the FNWC-PE model demonstrated similar or better performance.

C. CONCLUSIONS

The Fleet Numerical Weather Central's operational sea-level pressure forecasts produced by the five-layer primitive-equation model do show systematic errors in forecasting extratropical cyclogenesis. They are:

(1) An underforecast of deepening rate in a majority of cases.

(2) A tendency to greatly underforecast the deepening rate in the 12-hour prognoses and then underforecast to a lesser degree or overforecast subsequent 12-hour changes.

(3) A tendency to forecast the cyclone track to the right of actual track.

(4) A tendency to forecast the 36-hour position to the south and west of the actual position.

The average errors observed gave rise to Klopfenstein's rule for improving the FNWC-PE 36-hour forecasts of cyclogenesis:

KLOPFENSTEIN'S RULE

Deepen the forecast central pressure by 5 mb and move the forecast position 2° north and 3° east.

This is a general rule which can be applied to any stage of cyclone development in any area.

D. SUGGESTIONS FOR FURTHER RESEARCH

The following topics are suggested for further research:

(1) Systematic verification of 500-mb prognoses.

(2) Systematic comparison of FNWC-PE and NMC-PE prognoses.

(3) Analysis of the source of systematic errors.

Table I. Total Area (105E-40E) - Comparison of 12-, 24- and 36-hour prognoses - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	12 hour	24 hour	36 hour
+40		1 (0.2)	4 (0.9)
+36		1 (0.2)	2 (0.5)
+32		4 (0.8)	2 (0.5)
+28		4 (0.8)	4 (0.9)
+24	3 (0.6)	4 (2.9)	11 (2.5)
+20	6 (1.2)	15 (3.1)	24 (5.4)
+16	26 (5.3)	32 (6.6)	41 (9.2)
+12	38 (7.8)	75 (15.5)	57 (12.8)
+8	107 (21.9)	91 (18.8)	72 (16.1)
+4	136 (27.9)	97 (20.0)	73 (16.4)
0	32 (6.4)	24 (5.0)	8 (1.8)
-4	61 (12.5)	52 (10.7)	58 (13.0)
-8	32 (6.4)	34 (7.0)	42 (9.4)
-12	11 (2.2)	22 (4.5)	18 (4.0)
-16	5 (1.0)	6 (1.2)	9 (2.0)
-20	2 (0.4)	4 (0.8)	3 (0.7)
-24			
-28		1 (0.2)	2 (0.5)
-32			
-36			
-40			
Not Fcst	29 (5.9)	7 (1.4)	16 (3.6)
Total	488	484	446

Summary

Under-forecast	316 (64.8)	334 (69.0)	290 (65.0)
Over-forecast	111 (22.8)	119 (24.6)	148 (33.2)
Within $\pm$ 4 mb	229 (46.9)	173 (35.7)	139 (31.2)

Table II. Average amounts of forecast error in mb: + indicates underforecast; - indicates overforecast

	0-12 Hours	0-24 Hours	0-36 Hours
Area 1	+4.2	+4.0	+5.4
Area 2	+3.0	+3.3	+1.1
Area 3	+5.4	+7.0	+6.7
Area 4	+3.2	+5.2	+3.5
Total Area	+3.4	+4.8	+5.3
Frontal Wave	+0.3	-0.3	+2.0
Wave	+2.1	+4.2	+3.7
Occluding	+5.1	+6.4	+7.5
Occluded	+1.6	+3.0	+1.4

Table III. Average 36-hour forecast position error in terms of degrees latitude and longitude from the verifying position.

Area 1	1.6°S - 2.1°W
Area 2	0.6°S - 2.0°W
Area 3	2.0°S - 3.0°W
Area 4	1.1°S - 2.2°W
Total Area	1.5°S - 2.4°W

Table IV. Total Area (105E-40E) - Time interval 0-12 hours - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	Cyclone Type				
	Frontal Wave	Wave	Occluding	Occluded	Combined
+40					
+36					
+32					
+28					
+24			3 (1.0)		3 (0.6)
+20			6 (2.0)		6 (1.2)
+16		1 (0.8)	24 (8.0)	1 (5.9)	26 (5.3)
+12	1 (2.4)	7 (5.4)	30 (10.0)		38 (7.8)
+8	6 (14.3)	26 (20.0)	72 (24.1)	3 (17.6)	107 (21.9)
+4	14 (33.3)	42 (32.3)	76 (25.4)	4 (23.5)	136 (27.9)
0	2 (4.8)	7 (5.4)	19 (6.4)	4 (23.5)	32 (6.4)
-4	9 (21.4)	21 (16.2)	28 (9.4)	3 (17.6)	61 (12.5)
-8	5 (11.9)	8 (6.2)	17 (5.7)	2 (11.8)	32 (6.4)
-12	1 (2.4)	3 (2.4)	7 (2.3)		11 (2.2)
-16	1 (2.4)	2 (1.6)	2 (0.7)		5 (1.0)
-20		1 (0.8)	1 (0.3)		2 (0.4)
-24					
-28					
-32					
-36					
-40					
Not Fcst	3 (7.1)	12 (9.2)	14 (4.7)		29 (5.9)
Total	42	130	299	17	488

Summary

Under-forecast	21 (50.0)	76 (58.5)	211 (70.6)	8 (47.1)	316 (64.8)
Over-forecast	16 (38.1)	35 (26.9)	55 (18.4)	5 (29.4)	111 (22.8)
Within $\pm$ 4 mb	25 (59.5)	70 (53.8)	123 (44.5)	11 (64.7)	229 (46.9)

Table V. Total Area (105E-40E) - Time interval 0-24 hours - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	Cyclone Type				
	Frontal Wave	Wave	Occluding	Occluded	Combined
+40			1 (0.3)		1 (0.2)
+36			1 (0.3)		1 (0.2)
+32			3 (0.9)	1 (1.7)	4 (0.8)
+28			4 (1.2)		4 (0.8)
+24			14 (4.2)		14 (2.9)
+20		1 (1.3)	14 (4.2)		15 (3.1)
+16		4 (5.2)	24 (7.2)	4 (6.8)	32 (6.6)
+12		13 (16.9)	56 (16.7)	6 (10.2)	75 (15.5)
+8	1 (7.7)	16 (20.8)	63 (18.8)	11 (18.6)	91 (18.8)
+4	6 (46.2)	18 (23.4)	62 (18.5)	11 (18.6)	97 (20.0)
0	1 (7.7)	5 (6.5)	10 (3.0)	8 (13.6)	24 (5.0)
-4	2 (15.4)	12 (15.6)	31 (9.3)	7 (11.9)	52 (10.7)
-8	2 (15.4)	3 (3.9)	23 (6.9)	6 (10.2)	34 (7.0)
-12	1 (7.7)	4 (5.2)	14 (4.2)	3 (5.1)	22 (4.5)
-16			5 (1.5)	1 (1.7)	6 (1.2)
-20			3 (0.9)	1 (1.7)	4 (0.8)
-24					
-28			1 (0.3)		1 (0.2)
-32					
-36					
-40					
Not Fcst		1 (1.3)	6 (1.8)		7 (1.4)
Total	13	77	335	59	484

Summary

Under-forecast	7 (53.9)	52 (67.5)	242 (72.2)	33 (75.9)	334 (69.0)
Over-forecast	5 (38.5)	19 (24.7)	77 (23.0)	18 (30.5)	119 (24.6)
Within ± 4 mb	9 (69.2)	35 (45.5)	103 (30.7)	36 (61.0)	173 (35.7)

Table VI. Total Area (105E-40E) Time interval 0-36 hours - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	Cyclone Type				
	Frontal Wave	Wave	Occluding	Occluded	Combined
+40			4 (1.6)		4 (0.9)
+36			1 (0.4)	1 (0.7)	2 (0.5)
+32			2 (0.8)		2 (0.5)
+28			4 (1.6)		4 (0.9)
+24		1 (2.9)	8 (3.0)	2 (1.4)	11 (2.5)
+20		1 (2.9)	15 (5.6)	8 (5.6)	24 (5.4)
+16		1 (2.9)	31 (11.7)	9 (6.3)	41 (9.2)
+12		4 (11.8)	38 (14.3)	15 (10.5)	57 (12.8)
+8	1(33.3)	10 (29.4)	43 (16.2)	18 (12.6)	72 (16.1)
+4		4 (11.8)	42 (15.8)	27 (18.9)	73 (16.4)
0		2 (5.8)	3 (1.2)	3 (2.1)	8 (1.8)
-4	1(33.3)	5 (14.7)	26 (9.8)	26 (18.2)	58 (13.0)
-8		4 (11.8)	24 (9.0)	14 (9.8)	42 (9.4)
-12		1 (2.9)	8 (3.0)	9 (6.3)	18 (4.0)
-16		1 (2.9)	3 (1.2)	5 (3.5)	9 (2.0)
-20			1 (0.4)	2 (1.4)	3 (0.7)
-24					
-28				2 (1.4)	2 (0.5)
-32					
-36					
-40					
Not Fcst	1(33.3)		13 (4.9)	2 (1.4)	16 (3.6)
Total	3	34	266	143	446

Summary

Under-forecast	1 (33.3)	21 (61.8)	188 (70.7)	80 (55.9)	290 (65.0)
Over-forecast	1 (33.3)	11 (32.4)	75 (28.2)	60 (42.0)	148 (33.2)
Within ± 4 mb	1 (33.3)	11 (32.4)	71 (26.7)	56 (39.2)	139 (31.2)

Table VII. Cyclogenesis Area 1 (105E-180) Time interval 0-12 hours - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	Cyclone Type				
	Frontal Wave	Wave	Occluding	Occluded	Combined
+40					
+36					
+32					
+28					
+24			2 (1.9)		2 (1.1)
+20			2 (1.9)		2 (1.1)
+16			8 (7.5)		8 (4.5)
+12		3 (6.0)	12 (11.3)		15 (8.5)
+8	2 (12.5)	11 (22.0)	24 (22.6)	2 (40.0)	39 (22.0)
+4	7 (43.6)	18 (36.0)	28 (24.1)		53 (29.9)
0	1 (6.3)	4 (8.0)	4 (2.8)	2 (40.0)	11 (6.2)
-4	4 (25.0)	6 (12.0)	11 (10.4)	1 (20.0)	22 (12.1)
-8	2 (12.5)	3 (6.0)	5 (4.7)		10 (5.6)
-12		1 (2.0)	3 (2.7)		4 (2.2)
-16			1 (0.9)		1 (0.6)
-20		1 (2.0)			1 (0.6)
-24					
-28					
-32					
-36					
-40					
Not Fcst		3 (6.0)	6 (5.7)		9 (5.1)
Total	16	50	106	5	177

Summary

	Frontal Wave	Wave	Occluding	Occluded	Combined
Under-forecast	9 (56.1)	32 (64.0)	76 (71.6)	2 (40.0)	119 (67.4)
Over-forecast	6 (33.5)	11 (22.0)	20 (18.8)	1 (20.0)	38 (21.4)
Within ± 4 mb	12 (75.0)	28 (56.0)	43 (40.6)	3 (60.0)	96 (54.2)

Table VIII. Cyclogenesis Area 1 (105E-180) Time interval 0-24 hours - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	Cyclone Type				
	Frontal Wave	Wave	Occluding	Occluded	Combined
+40			1 (0.8)		1 (0.5)
+36			1 (0.8)		1 (0.5)
+32			2 (1.6)		2 (1.1)
+28			2 (1.6)		2 (1.1)
+24			4 (3.2)		4 (2.2)
+20			4 (3.2)		4 (2.2)
+16		1 (3.3)	11 (8.8)	1 (5.6)	13 (7.1)
+12		2 (6.6)	18 (14.4)	2 (11.1)	22 (11.0)
+8	1 (16.7)	7 (21.2)	15 (12.0)	1 (5.6)	24 (13.2)
+4	3 (50.0)	11 (33.3)	25 (20.0)	5 (27.8)	44 (24.2)
0	1 (16.7)	2 (6.6)	6 (4.8)	4 (22.2)	13 (7.1)
-4	1 (16.7)	6 (18.4)	15 (12.0)	2 (11.1)	24 (13.2)
-8		1 (3.3)	9 (7.2)	3 (16.6)	13 (7.1)
-12		3 (9.2)	7 (5.6)		10 (5.4)
-16			2 (1.6)		2 (1.1)
-20			2 (1.6)		2 (1.1)
-24					
-28					
-32					
-36					
-40					
Not Fcst			1 (0.8)		1 (0.5)
Total	6	33	125	18	182

Summary

Under-forecast	4 (33.3)	21 (63.6)	83 (66.4)	9 (50.0)	117 (64.3)
Over-forecast	1 (16.7)	10 (30.3)	35 (28.0)	5 (27.8)	51 (28.0)
Within ± 4 mb	5 (83.3)	19 (57.6)	46 (36.8)	11 (61.2)	81 (44.5)

Table IX. Cyclogenesis Area 1 (105E-180) Time interval 0-36 hours - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	Cyclone Type				
	Frontal Wave	Wave	Occluding	Occluded	Combined
+40			2 (1.8)		2 (1.1)
+36					
+32			1 (0.9)		1 (0.6)
+28			2 (1.8)		2 (1.1)
+24			2 (1.8)	1 (2.2)	3 (1.8)
+20			10 (9.0)	5 (11.1)	15 (8.7)
+16			18 (16.2)	3 (6.6)	21 (12.1)
+12		3 (20.0)	15 (13.5)	4 (8.8)	22 (12.7)
+8		6 (40.0)	13 (11.7)	5 (11.1)	24 (13.9)
+4		2 (13.3)	15 (13.5)	4 (8.8)	21 (12.1)
0			1 (0.9)		1 (0.6)
-4	1 (50.0)	2 (13.3)	11 (9.9)	10 (22.2)	24 (13.9)
-8		1 (6.7)	8 (7.2)	7 (15.5)	16 (9.2)
-12		1 (6.7)	6 (5.4)	3 (6.6)	10 (5.8)
-16			1 (0.9)	1 (2.2)	2 (1.1)
-20			1 (0.9)		1 (0.6)
-24					
-28					
-32					
-36					
-40					
Not Fcst	1 (50.0)		5 (4.5)	2 (4.4)	8 (4.6)
Total	2	15	111	45	173

Summary

Under-forecast		11 (73.4)	78 (70.2)	22 (49.0)	111 (64.2)
Over-forecast	1 (50.0)	4 (26.9)	27 (24.3)	21 (46.7)	53 (30.6)
Within $\pm$ 4 mb	1 (50.0)	4 (26.9)	27 (24.3)	14 (31.1)	46 (26.6)

Table X. Cyclogenesis Area 2 (180-110W) Time interval 0-12 hours - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	Cyclone Type				
	Frontal Wave	Wave	Occluding	Occluded	Combined
+40					
+36					
+32					
+28					
+24					
+20			1 (2.2)		1 (1.4)
+16			3 (6.5)		3 (4.3)
+12			7 (15.2)		7 (10.1)
+8	1 (20.0)	3 (17.6)	8 (17.3)		12 (17.4)
+4	2 (40.0)	4 (23.5)	13 (28.2)		19 (27.5)
0			2 (4.3)	1 (100.0)	3 (4.3)
-4	2 (40.0)	4 (23.5)	3 (6.5)		9 (13.0)
-8		2 (11.7)	4 (8.7)		6 (8.7)
-12		1 (5.9)	1 (22.2)		2 (2.9)
-16		2 (11.7)			2 (2.9)
-20					
-24					
-28					
-32					
-36					
-40					
Not Fcst		2 (11.7)	4 (8.7)		6 (8.7)
Total	5	17	46	1	69

Summary

Under-forecast	3 (60.0)	7 (41.2)	32 (69.6)		42 (60.9)
Over-forecast	2 (40.0)	9 (52.9)	8 (17.4)		19 (27.5)
Within $\pm$ 4 mb	4 (80.0)	8 (47.0)	18 (39.2)	1 (100.0)	31 (44.9)

Table XI. Cyclogenesis Area 2 (180-110W) Time interval 0-24 hours - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	Cyclone Type				
	Frontal Wave	Wave	Occluding	Occluded	Combined
+40					
+36					
+32					
+28					
+24			1 (1.9)		1 (1.4)
+20			2 (3.8)		2 (2.9)
+16		1 (12.5)	2 (3.8)		3 (4.3)
+12		2 (25.0)	7 (13.5)		9 (12.8)
+8		1 (12.5)	11 (21.2)	1 (10.0)	13 (18.6)
+4	1 (100.0)	1 (12.5)	18 (34.6)	2 (20.0)	22 (31.4)
0		1 (12.5)		3 (30.0)	4 (5.8)
-4		1 (12.5)	4 (7.7)	1 (10.0)	6 (8.7)
-8		1 (12.5)	1 (1.9)	1 (10.0)	3 (4.3)
-12			1 (1.9)	1 (10.0)	2 (2.9)
-16			2 (3.8)		2 (2.9)
-20			1 (1.9)	1 (10.0)	2 (2.9)
-24					
-28			1 (1.9)		1 (1.4)
-32					
-36					
-40					
Not Fcst			1 (1.9)		1 (1.4)
Total	1	8	52	10	70

Summary

Under-forecast	1 (100.0)	5 (62.5)	41 (79.0)	3 (30.0)	50 (71.5)
Over-forecast		2 (25.0)	10 (19.2)	4 (40.0)	16 (22.9)
Within $\pm$ 4 mb	1 (100.0)	3 (37.5)	33 (63.5)	6 (60.0)	32 (45.7)

Table XII. Cyclogenesis Area 2 (180-110W) Time interval 0-36 hours - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	Cyclone Type				
	Frontal Wave	Wave	Occluding	Occluded	Combined
+40					
+36					
+32			1 (3.1)		1 (1.5)
+28					
+24					
+20					
+16		1 (25.0)	3 (9.4)	1 (3.2)	5 (7.5)
+12			2 (6.2)	4 (12.9)	6 (9.0)
+8		1 (25.0)	4 (12.5)	3 (9.7)	8 (11.9)
+4			8 (25.0)	9 (29.0)	17 (25.4)
0			1 (3.1)	1 (3.2)	2 (3.0)
-4		1 (25.0)	5 (15.6)	4 (12.9)	10 (14.9)
-8			5 (15.6)	1 (3.2)	6 (9.0)
-12				5 (16.1)	5 (7.5)
-16		1 (25.0)	1 (3.1)	1 (3.2)	3 (4.5)
-20				1 (3.2)	1 (1.5)
-24					
-28				1 (3.2)	1 (1.5)
-32					
-36					
-40					
Not Fcst			2 (6.2)		2 (3.0)
Total		4	32	31	67

Summary

	Frontal Wave	Wave	Occluding	Occluded	Combined
Under-forecast		2 (50.0)	18 (56.3)	17 (54.9)	37 (55.3)
Over-forecast		2 (50.0)	11 (26.2)	13 (42.0)	26 (38.8)
Within $\pm$ 4 mb		1 (25.0)	14 (43.7)	14 (45.2)	29 (43.3)

Table XIII. Cyclogenesis Area 3 (110W-60W) Time interval 0-12 hours - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	Cyclone Type				
	Frontal Wave	Wave	Occluding	Occluded	Combined
+40					
+36					
+32					
+28					
+24					
+20			3 (3.3)		3 (2.0)
+16		1 (2.1)	9 (9.9)	1 (33.3)	11 (7.2)
+12		3 (6.4)	8 (8.8)		11 (7.2)
+8	1 (8.3)	9 (19.1)	25 (27.5)		35 (22.8)
+4	4 (33.3)	14 (29.8)	25 (27.5)	1 (33.3)	44 (28.5)
0	1 (8.3)	3 (6.4)	6 (6.6)		10 (6.5)
-4	3 (25.0)	9 (19.1)	7 (7.7)		19 (12.4)
-8	3 (25.0)	2 (4.2)	5 (5.5)	1 (33.3)	11 (7.2)
-12		1 (2.1)	3 (3.3)		4 (2.6)
-16					
-20					
-24					
-28					
-32					
-36					
-40					
Not Fcst		5 (10.7)			5 (3.3)
Total	12	47	91	3	153

Summary

Under-forecast	5 (41.6)	27 (57.4)	70 (77.0)	2 (66.7)	104 (68.0)
Over-forecast	6 (50.0)	12 (25.6)	15 (16.5)	1 (33.3)	34 (21.3)
Within ± 4 mb	8 (66.7)	26 (55.3)	38 (41.7)	0	73 (47.6)

Table XIV. Cyclogenesis Area 3 (110W-60W) Time interval 0-24 hours - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	Cyclone Type				
	Frontal Wave	Wave	Occluding	Occluded	Combined
+40					
+36					
+32				1 (7.1)	1 (0.7)
+28			1 (1.0)		1 (0.7)
+24			8 (8.0)		8 (5.5)
+20		1 (3.6)	8 (8.0)		9 (6.2)
+16			8 (8.0)	2 (14.3)	10 (6.9)
+12		6 (21.4)	19 (19.0)	4 (28.6)	29 (20.1)
+8		7 (25.0)	19 (19.0)	3 (21.4)	29 (20.1)
+4		4 (14.2)	13 (13.0)	1 (7.1)	18 (12.5)
0		2 (7.1)	4 (4.0)		6 (4.2)
-4	1 (50.0)	5 (17.8)	8 (8.0)	1 (7.1)	15 (10.4)
-8	1 (50.0)	1 (3.6)	6 (6.0)	1 (7.1)	9 (6.2)
-12		1 (3.6)	3 (3.0)		4 (2.8)
-16				1 (7.1)	1 (7.1)
-20					
-24					
-28					
-32					
-36					
-40					
Not Fcst		1 (3.6)	1 (1.0)		2 (1.4)
Total	2	28	100	14	144

Summary

	Frontal Wave	Wave	Occluding	Occluded	Combined
Under-forecast		18 (64.3)	76 (76.0)	11 (78.6)	105 (72.9)
Over-forecast	2 (100.0)	7 (25.0)	17 (17.0)	3 (21.4)	29 (20.1)
Within ± 4 mb	1 (50.0)	11 (39.2)	25 (25.0)	2 (14.3)	39 (27.1)

Table XV. Cyclogenesis Area 3 (110W-60W) Time interval 0-36 hours - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	Cyclone Type				
	Frontal Wave	Wave	Occluding	Occluded	Combined
+40			2 (2.5)		2 (1.6)
+36			1 (1.2)	1 (2.8)	2 (1.6)
+32					
+28			2 (2.5)		2 (1.6)
+24			5 (6.2)		5 (3.9)
+20		1 (7.7)	3 (3.7)	2 (5.6)	6 (4.7)
+16			7 (8.6)	4 (11.4)	11 (8.5)
+12			17 (21.0)	5 (14.3)	22 (17.0)
+8		3 (23.1)	16 (19.8)	4 (11.4)	23 (17.8)
+4		2 (15.4)	9 (11.1)	5 (14.3)	16 (12.4)
0		2 (15.4)	1 (1.2)	1 (2.8)	4 (3.1)
-4		2 (15.4)	6 (7.4)	6 (16.1)	14 (10.8)
-8		3 (23.1)	7 (8.6)	5 (14.3)	15 (11.6)
-12			1 (1.2)		1 (0.8)
-16			1 (1.2)	1 (2.8)	2 (1.6)
-20			1 (1.2)	1 (2.8)	2 (1.6)
-24					
-28				1 (2.8)	1 (0.8)
-32					
-36					
-40					
Not Fcst			3 (3.7)		3 (2.4)
Total		13	81	35	129

Summary

	Frontal Wave	Wave	Occluding	Occluded	Combined
Under-forecast		6 (46.2)	62 (76.5)	21 (60.0)	89 (69.0)
Over-forecast		5 (38.5)	15 (18.5)	13 (37.2)	33 (25.6)
Within $\pm$ 4 mb		6 (46.2)	16 (19.7)	12 (34.2)	34 (26.4)

Table XVI. Cyclogenesis Area 4 (60W-40E) Time interval 0-12 hours - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	Cyclone Type				
	Frontal Wave	Wave	Occluding	Occluded	Combined
+40					
+36					
+32					
+28					
+24			1 (1.7)		1 (1.1)
+20					
+16			4 (7.1)		4 (4.5)
+12	1 (11.1)	1 (6.7)	3 (5.4)		5 (5.6)
+8	2 (22.2)	3 (20.0)	15 (26.8)	1 (12.5)	21 (23.8)
+4	1 (11.1)	6 (40.0)	10 (17.9)	3 (37.5)	20 (22.7)
0			7 (12.5)	1 (12.5)	8 (9.1)
-4		2 (13.3)	7 (12.5)	2 (25.0)	11 (12.5)
-8		1 (6.7)	3 (5.4)	1 (12.5)	5 (5.7)
-12	1 (11.1)				1 (1.1)
-16	1 (11.1)		1 (1.7)		2 (2.3)
-20			1 (1.7)		2 (1.1)
-24					
-28					
-32					
-36					
-40					
Not Fcst	3 (33.3)	2 (13.3)	4 (7.1)		9 (10.2)
Total	9	15	56	8	88

Summary

Under-forecast	4 (44.5)	10 (66.7)	33 (59.0)	4 (50.0)	50 (56.9)
Over-forecast	2 (22.2)	3 (20.0)	12 (21.5)	3 (37.5)	20 (22.7)
Within ± 4 mb	1 (11.1)	8 (53.3)	24 (42.9)	6 (75.0)	39 (44.3)

Table XVII. Cyclogenesis Area 4 (60W-40E) Time interval 0-24 hours - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	Cyclone Type				
	Frontal Wave	Wave	Occluding	Occluded	Combined
+40					
+36					
+32			1 (1.7)		1 (1.1)
+28			1 (1.7)		1 (1.1)
+24			1 (1.7)		1 (1.1)
+20					
+16		2 (22.2)	3 (5.2)	1 (5.9)	6 (6.7)
+12		3 (33.4)	12 (20.7)		15 (17.1)
+8		2 (22.2)	19 (32.8)	6 (35.3)	27 (30.7)
+4	2 (50.0)	2 (22.2)	4 (6.9)	3 (17.6)	11 (12.5)
0				1 (5.9)	1 (1.1)
-4			4 (6.9)	3 (17.6)	7 (9.9)
-8	1 (25.0)		7 (12.1)	1 (5.9)	9 (10.2)
-12	1 (25.0)		2 (3.4)	2 (11.7)	5 (5.7)
-16			1 (1.7)		1 (1.1)
-20					
-24					
-28					
-32					
-36					
-40					
Not Fcst			3 (5.2)		3 (3.3)
Total	4	9	58	17	88

Summary

	Frontal Wave	Wave	Occluding	Occluded	Combined
Under-forecast	2 (50.0)	9 (100.0)	41 (70.7)	10 (58.5)	62 (70.5)
Over-forecast	2 (50.0)		14 (24.1)	6 (35.3)	22 (25.0)
Within $\pm$ 4 mb	2 (50.0)	2 (22.2)	8 (13.8)	6 (35.3)	19 (21.6)

Table XVIII. Cyclogenesis Area 4 (60W-40E) Time interval 0-36 hours - parentheses indicate percent; numbers indicate cases observed.

Error in deepening rate in mb	Cyclone Type				
	Frontal Wave	Wave	Occluding	Occluded	Combined
+40					
+36					
+32					
+28					
+24		1 (50.0)	1 (2.9)	1 (3.1)	3 (4.3)
+20			2 (5.7)	1 (3.1)	3 (4.3)
+16			3 (8.6)	1 (3.1)	4 (5.7)
+12		1 (50.0)	3 (8.6)	2 (6.3)	6 (8.6)
+8	1 (100.0)		4 (11.4)	6 (18.7)	11 (15.7)
+4			10 (28.6)	9 (28.4)	19 (27.2)
0				1 (3.1)	1 (1.4)
-4			4 (11.4)	6 (18.7)	10 (14.3)
-8			4 (11.4)	1 (3.1)	5 (7.1)
-12			1 (2.9)	1 (3.1)	2 (2.9)
-16				2 (6.3)	2 (2.9)
-20				1 (3.1)	1 (1.4)
-24					
-28					
-32					
-36					
-40					
Not Fcst			3 (8.6)		3 (4.3)
Total	1	2	35	32	70

Summary

Under-forecast	1 (100.0)	2 (100.0)	23 (65.7)	20 (62.5)	46 (65.7)
Over-forecast			9 (25.7)	11 (34.4)	20 (28.6)
Within ± 4 mb			14 (40.0)	16 (50.0)	30 (42.9)

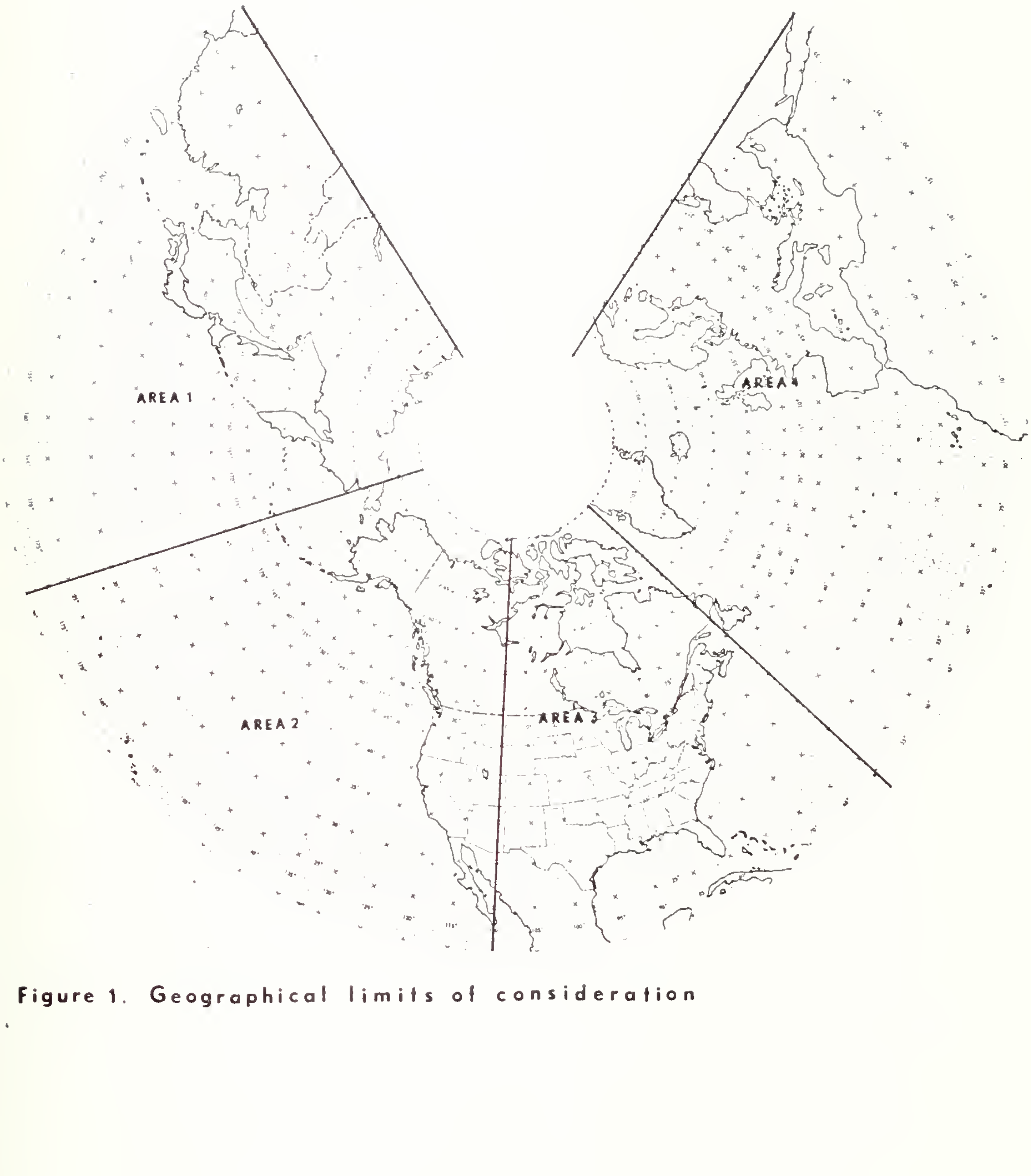


Figure 1. Geographical limits of consideration

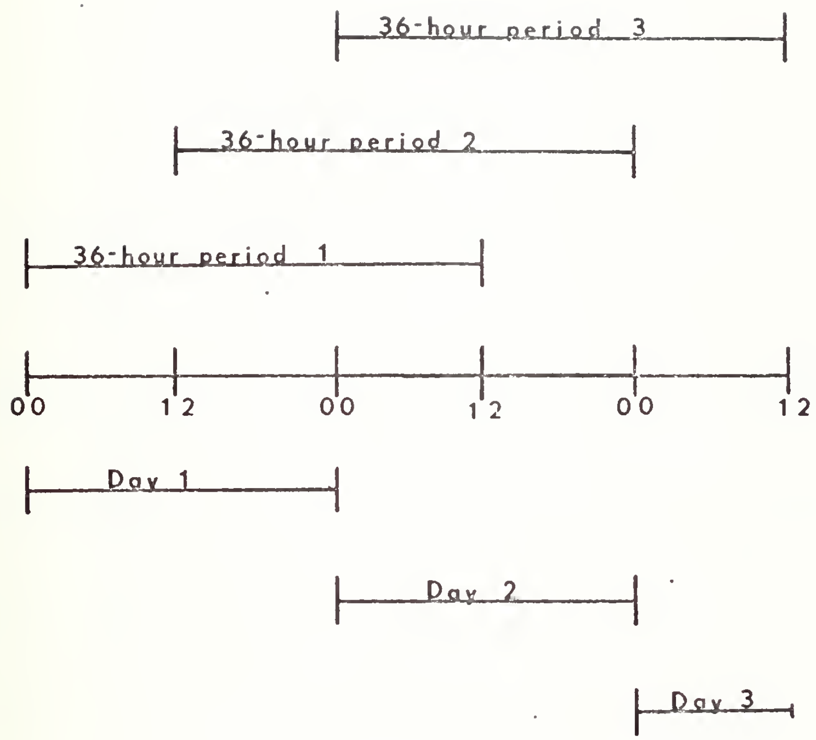


Figure 2. Determination of comparison periods

CYCLOGENESIS AREA ______________

NO	0000	LAT	LONG	CP		06	CP		1200	LAT	LONG	CP		18	CP	

IP	DTG	12	LAT	LONG	CP		24	LAT	LONG	CP		36	LAT	LONG	CP

		IP	12	24	36
DTG		CP / CHG	CP / CHG	CP / CHG	CP / CHG
	OBS				
	FCST				
	OBS				
	FCST				

12 - HOUR VERIFYING TIME

	12	24	36

Figure 3. Formats used for data collection and reduction to changes in central pressure.

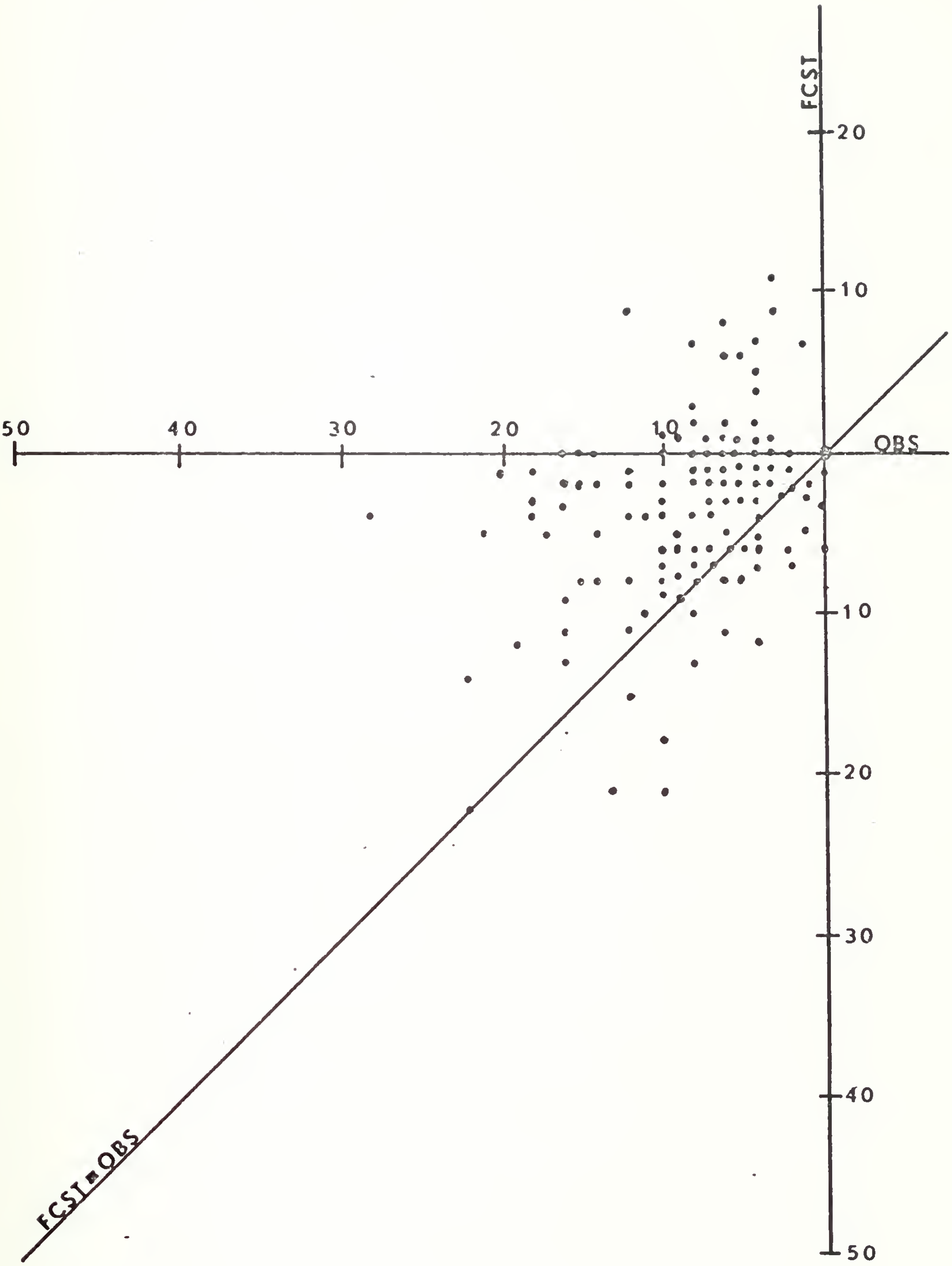


Figure 4. Cyclogenesis Area 1 (105E-180) - Time interval 0-12 hours. Forecast versus observed deepening rate in mb.

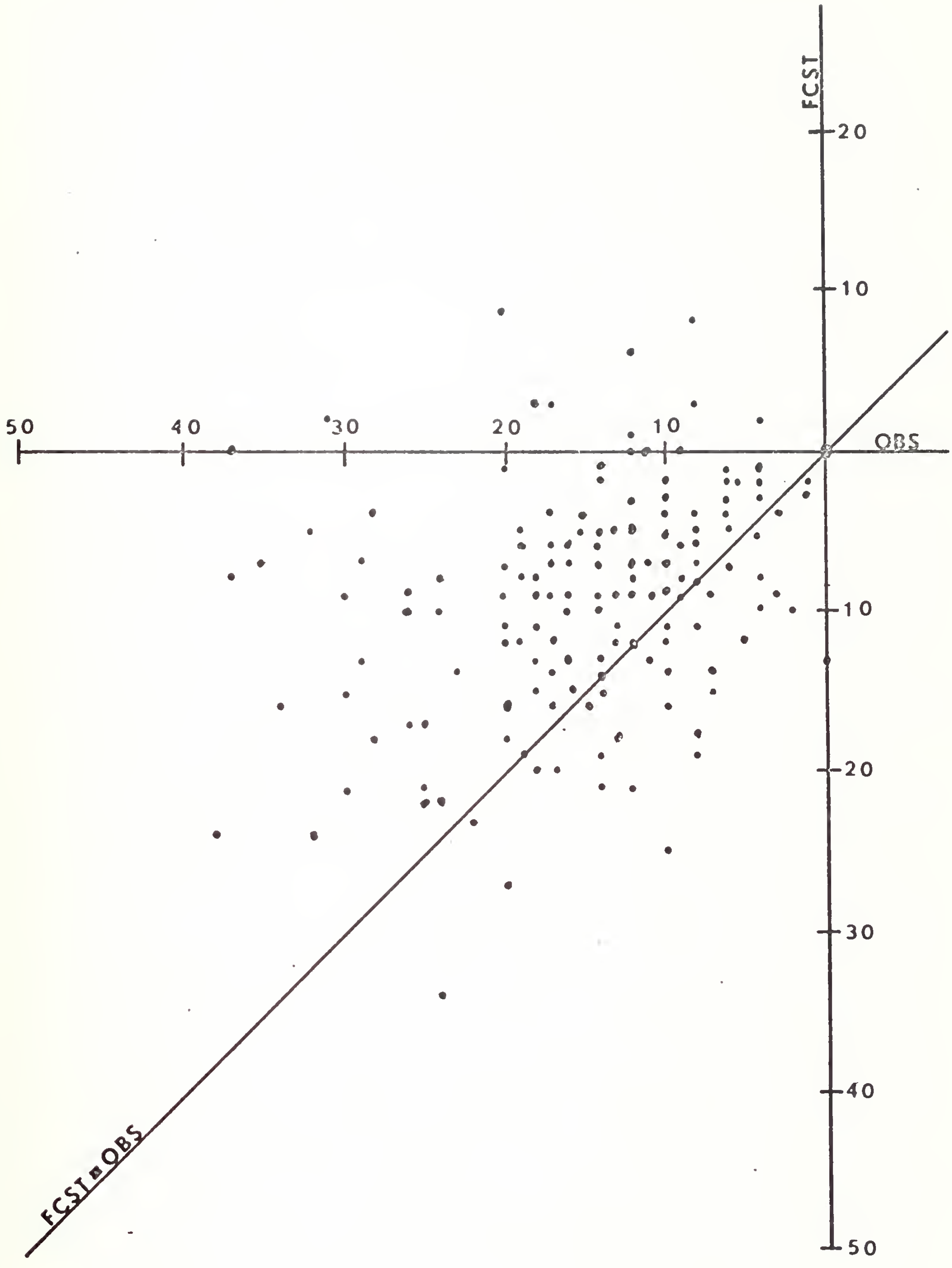


Figure 5. Cyclogenesis Area 1 (105E-180) - Time interval 0-24 hours. Forecast versus observed deepening rate in mb.

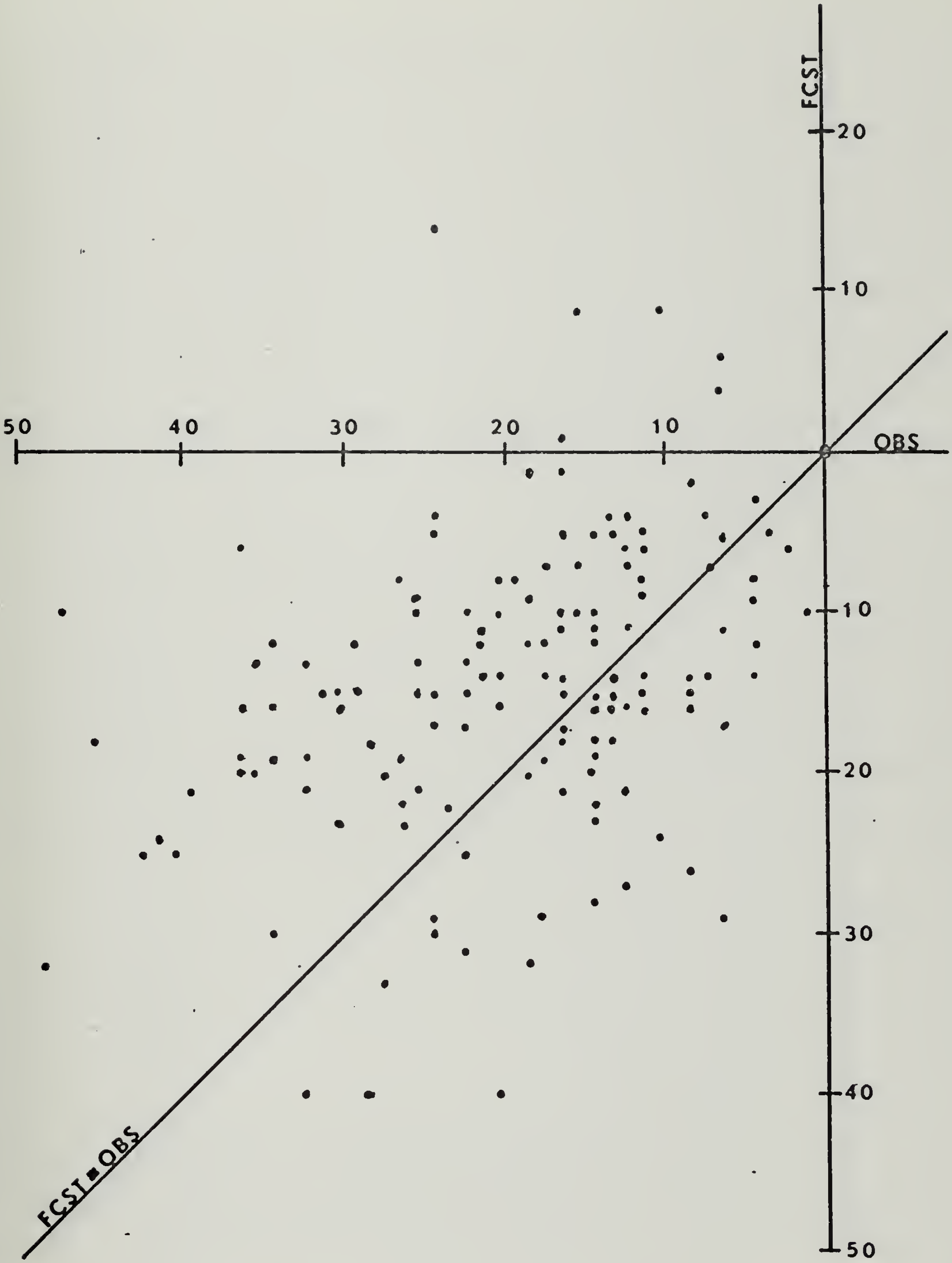


Figure 6. Cyclogenesis Area 1 (105E-180) - Time interval 0-36 hours. Forecast versus observed deepening rate in mb.

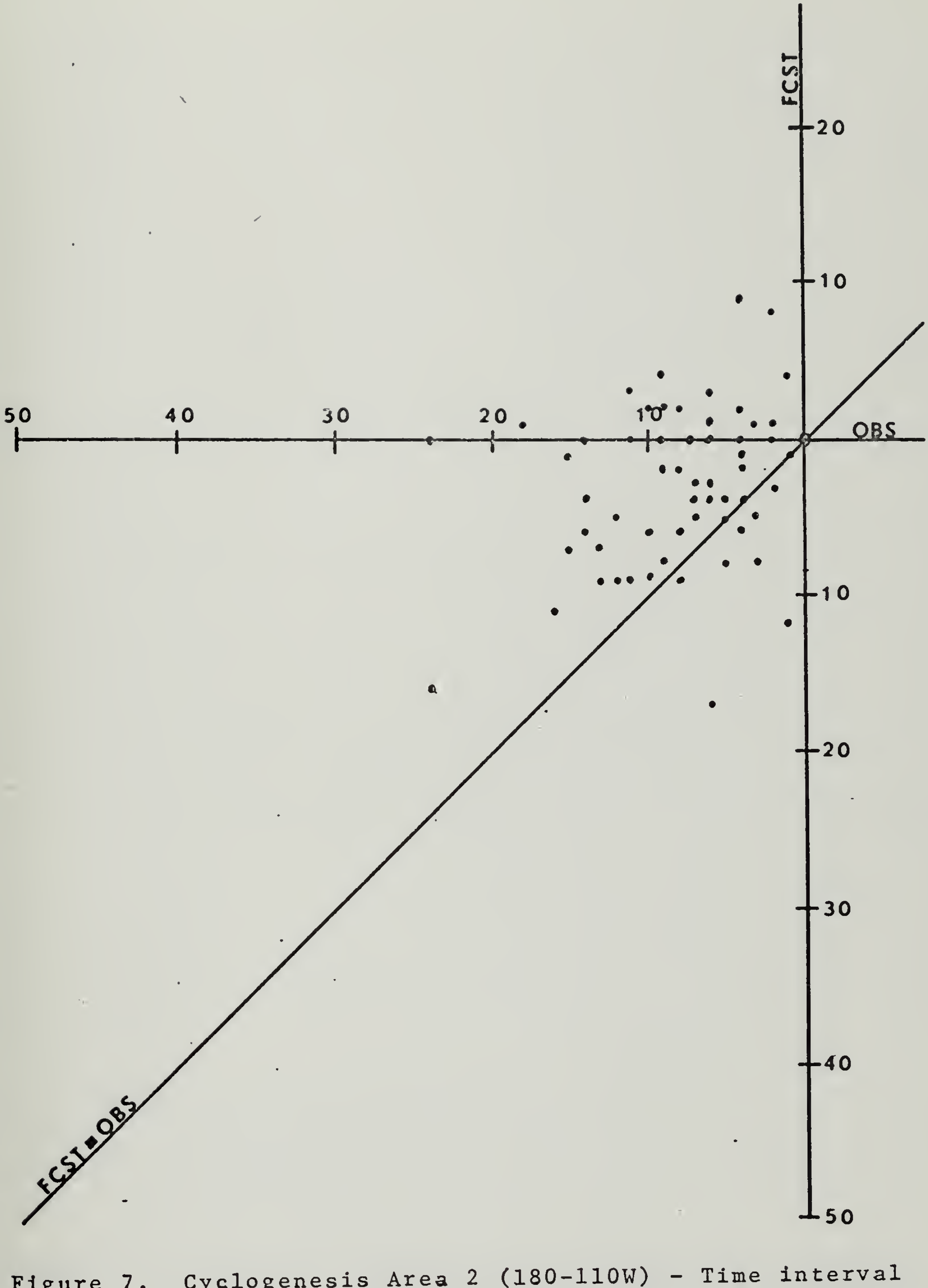


Figure 7. Cyclogenesis Area 2 (180-110W) - Time interval 0-12 hours. Forecast versus observed deepening rate in mb.

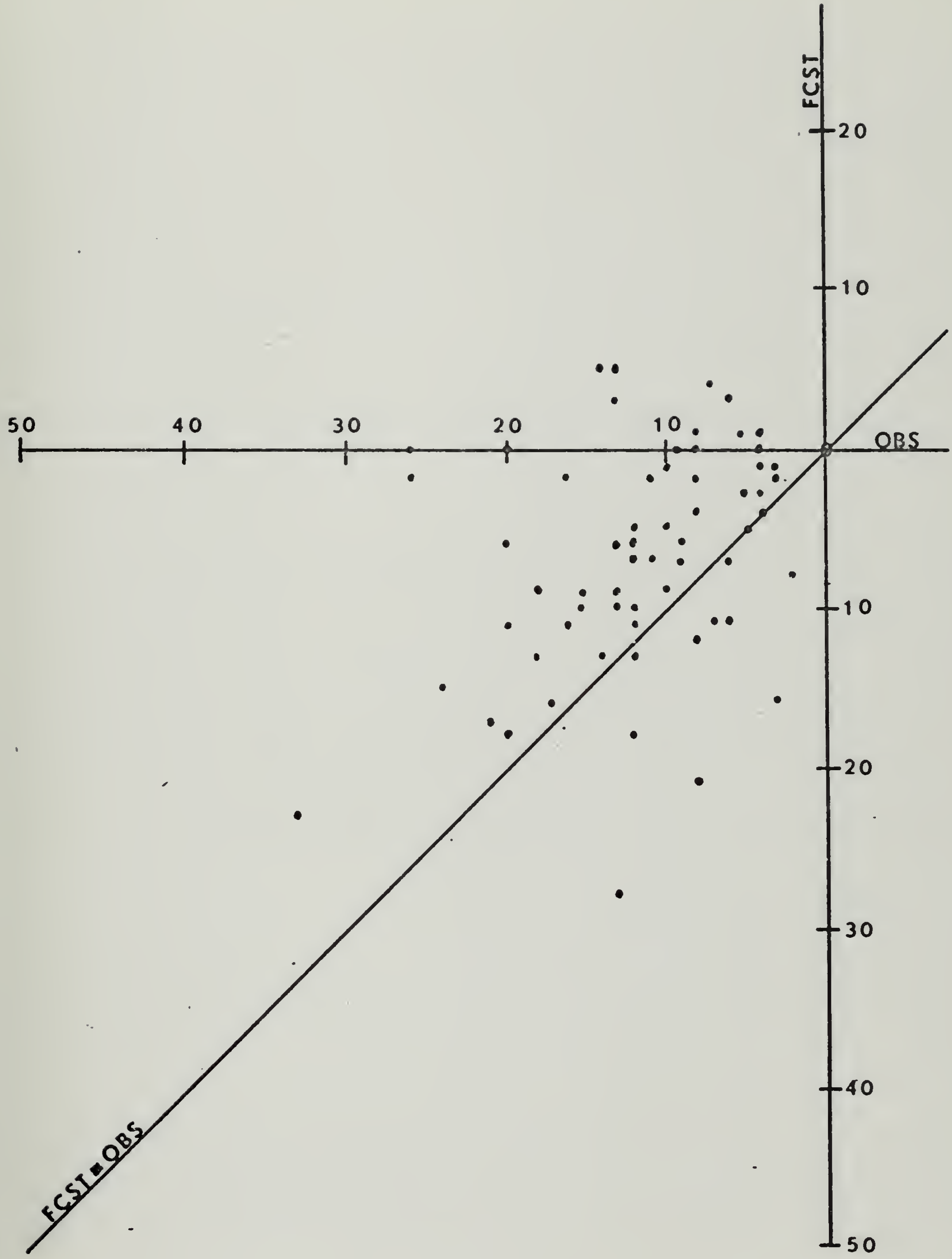


Figure 8. Cyclogenesis Area 2 (180-110W) - Time interval 0-24 hours. Forecast versus observed deepening rate in mb.

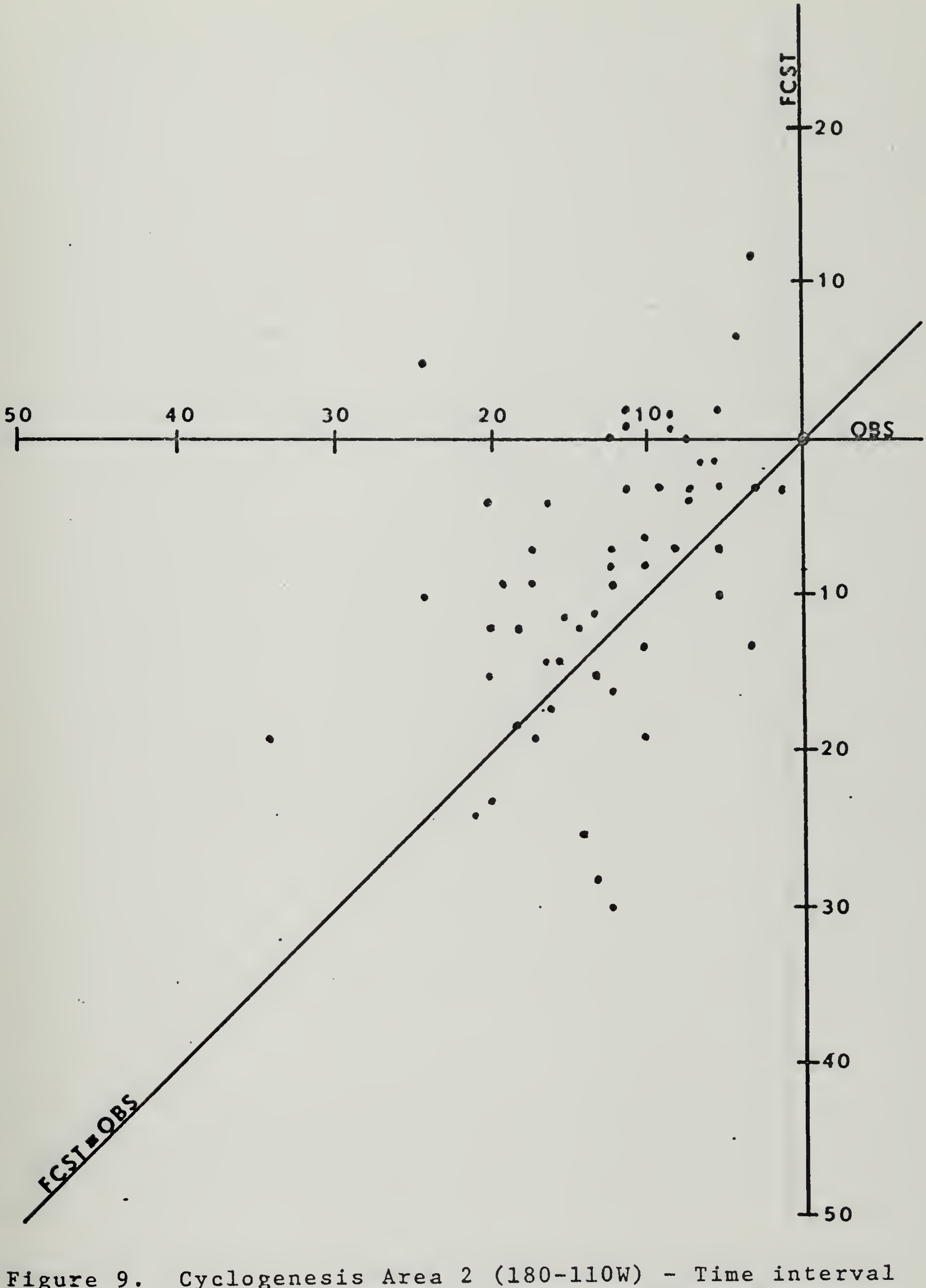


Figure 9. Cyclogenesis Area 2 (180-110W) - Time interval 0-36 hours. Forecast versus observed deepening rate in mb.

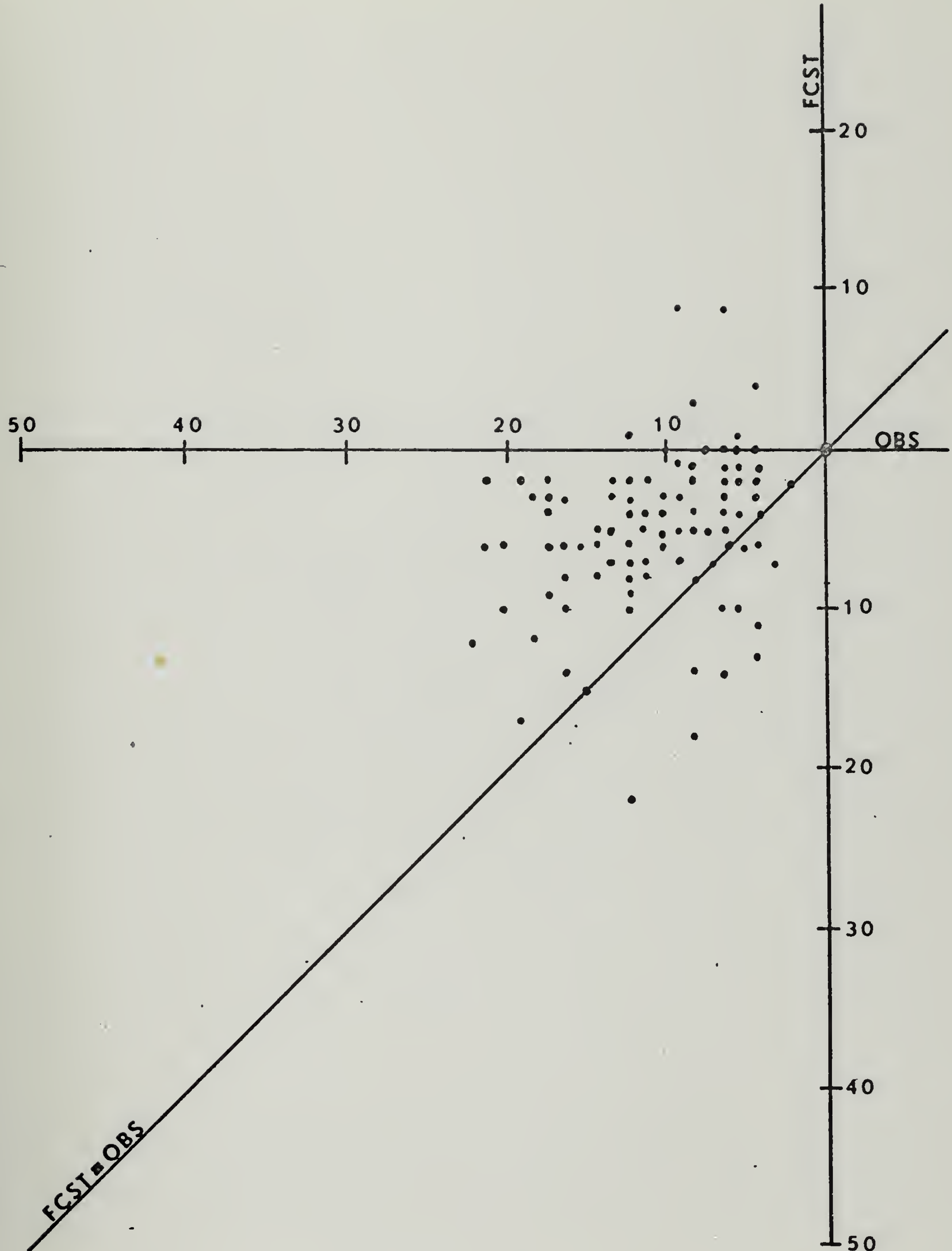


Figure 10. Cyclogenesis Area 3 (110W-60W) - Time interval 0-12 hours. Forecast versus observed deepening rate in mb.

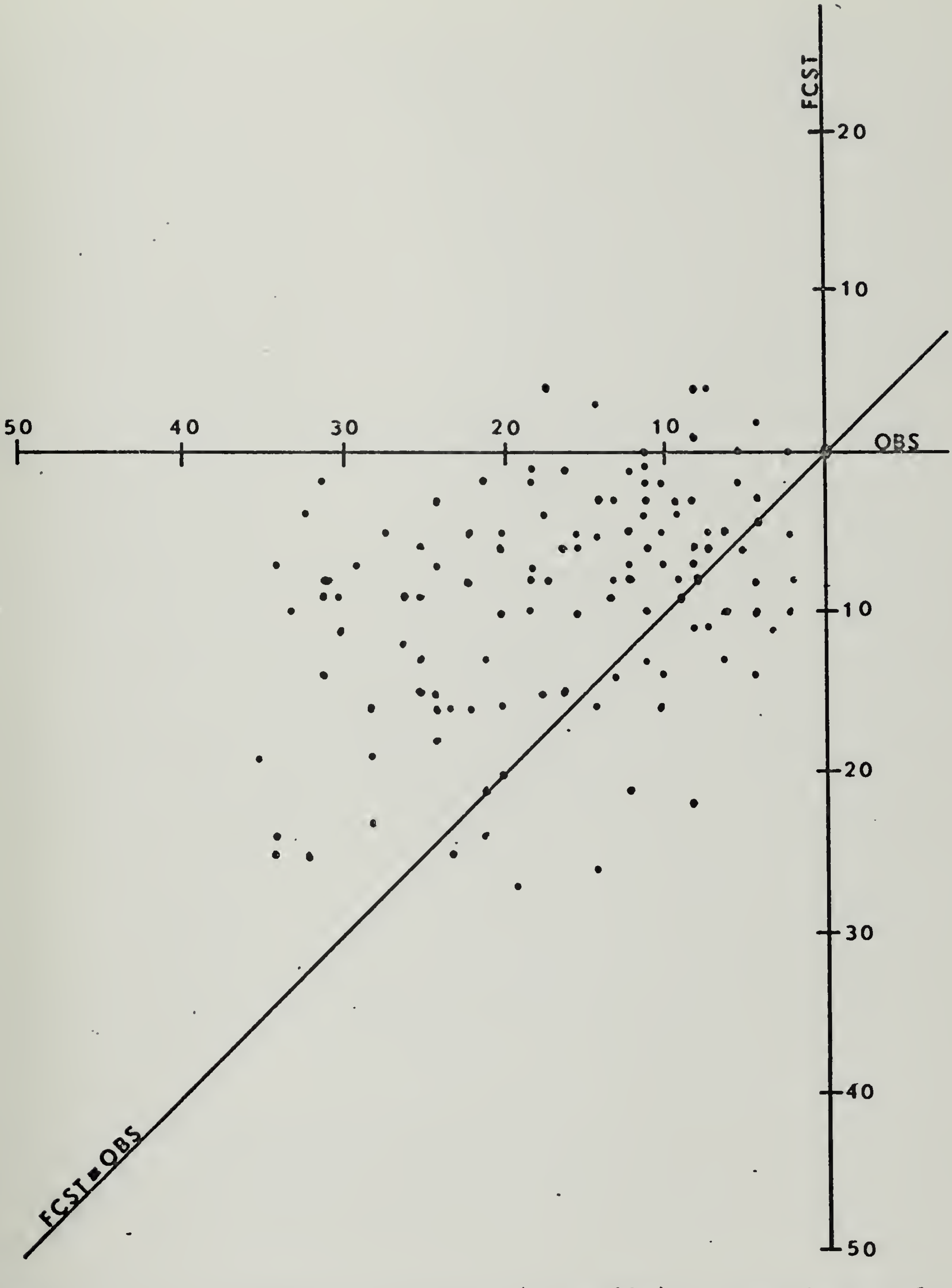


Figure 11. Cyclogenesis Area 3 (110W-60W) - Time interval 0-24 hours. Forecast versus observed deepening rate in mb.

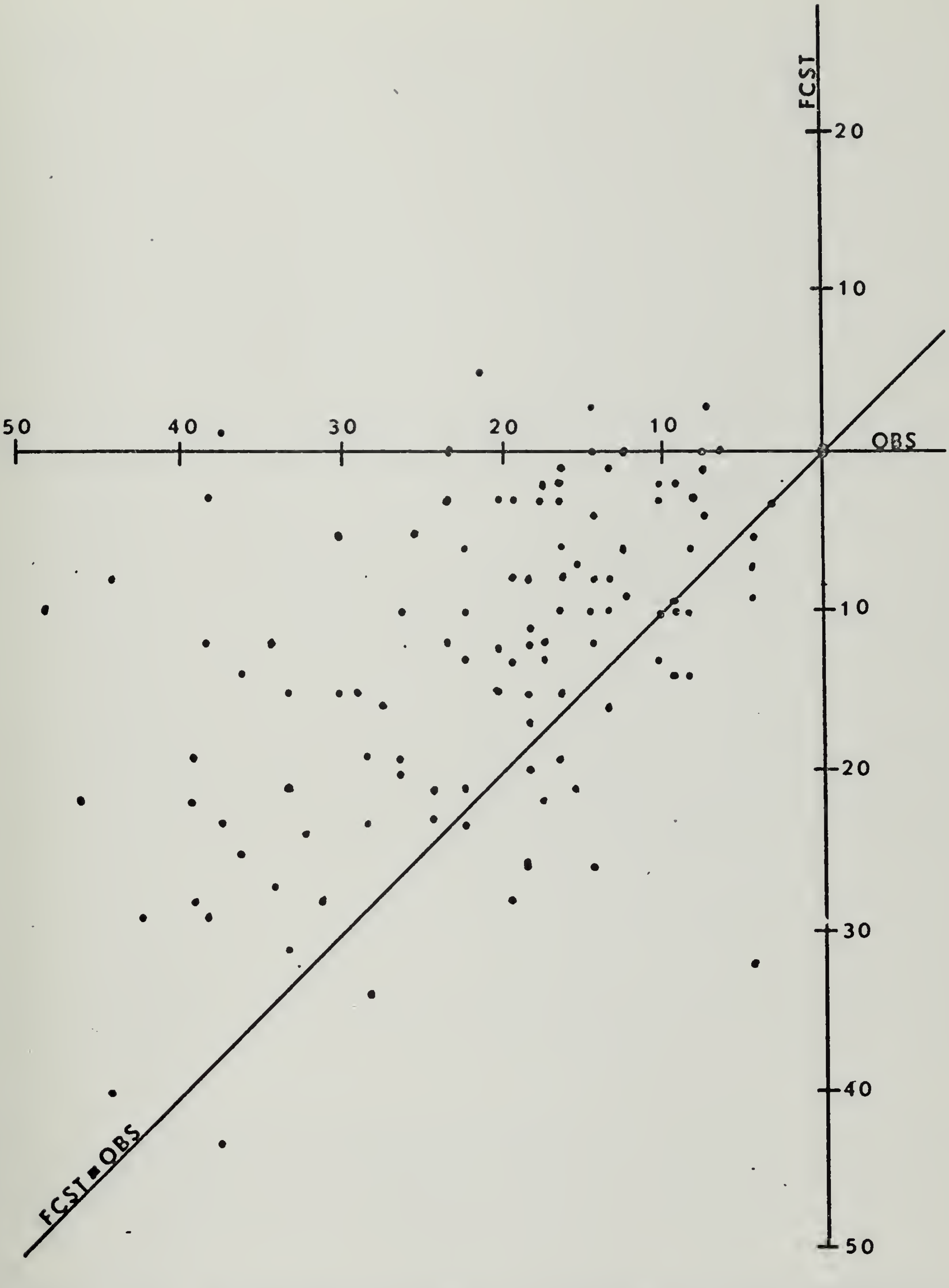


Figure 12. Cyclogenesis Area 3 (110W-60W) - Time interval 0-36 hours. Forecast versus observed deepening rate in mb.

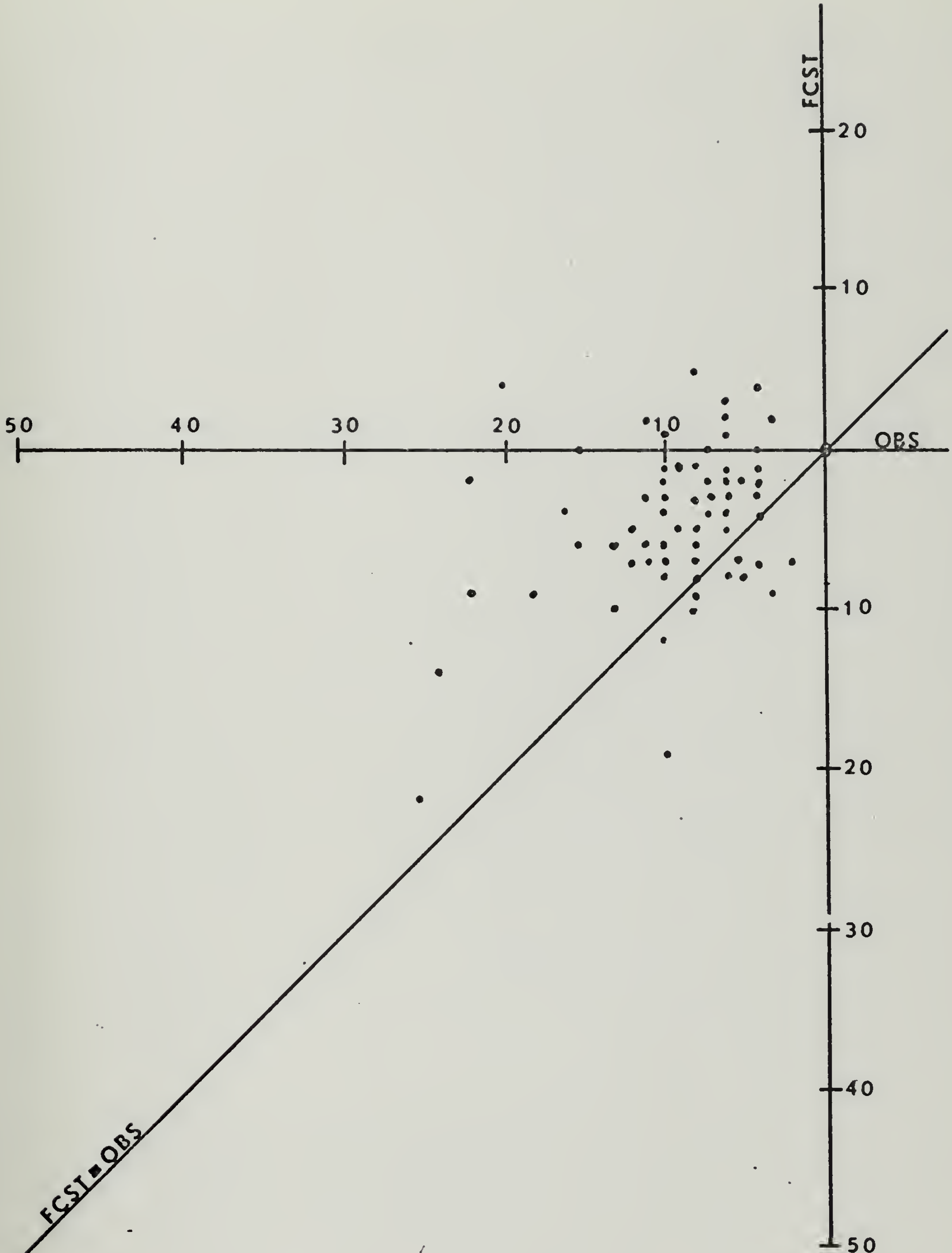


Figure 13. Cyclogenesis Area 4 (60W-40E) - Time interval 0-12 hours. Forecast versus observed deepening rate in mb.

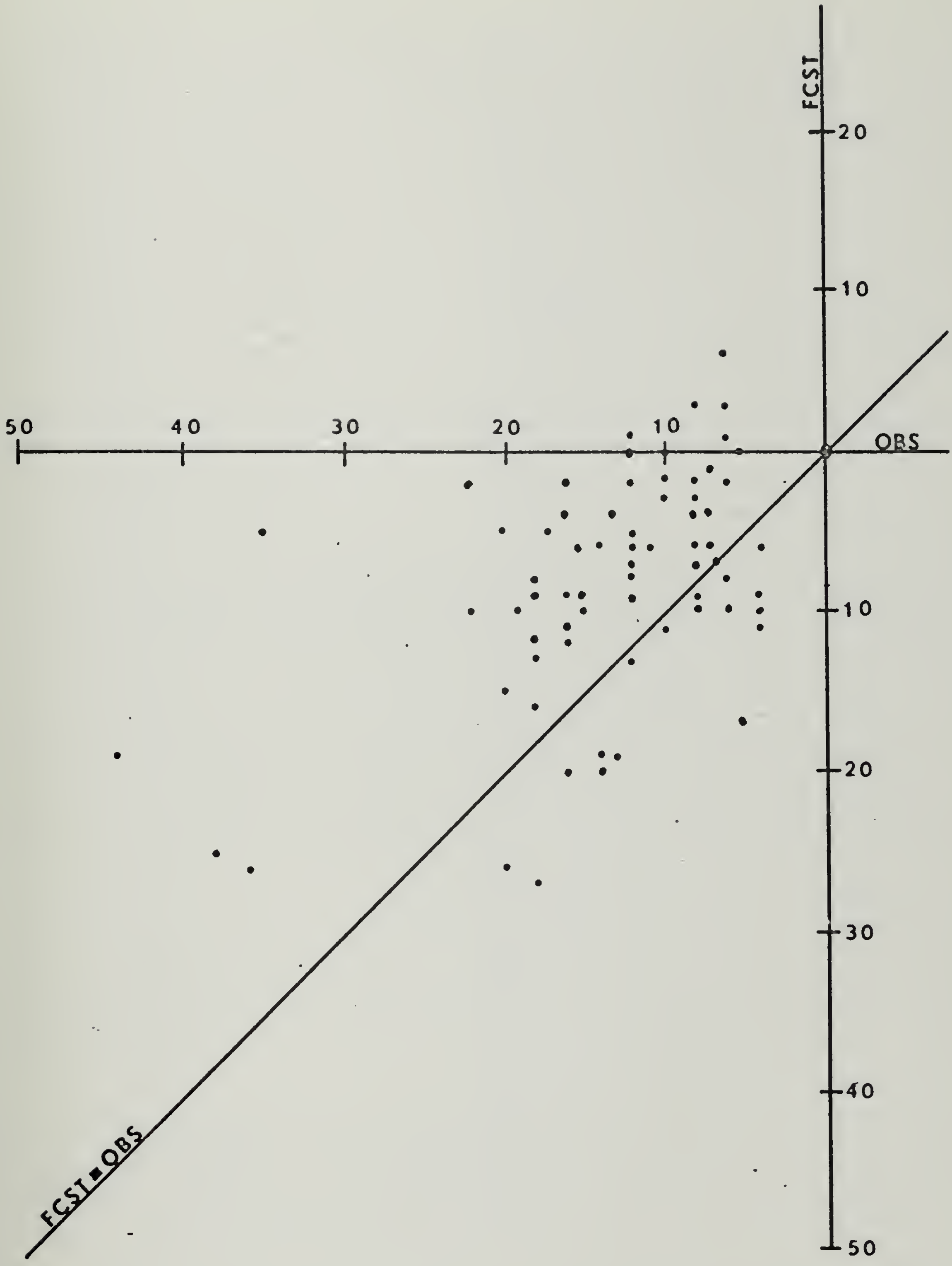


Figure 14. Cyclogenesis Area 4 (60W-40E) - Time interval 0-24 hours. Forecast versus observed deepening rate in mb.

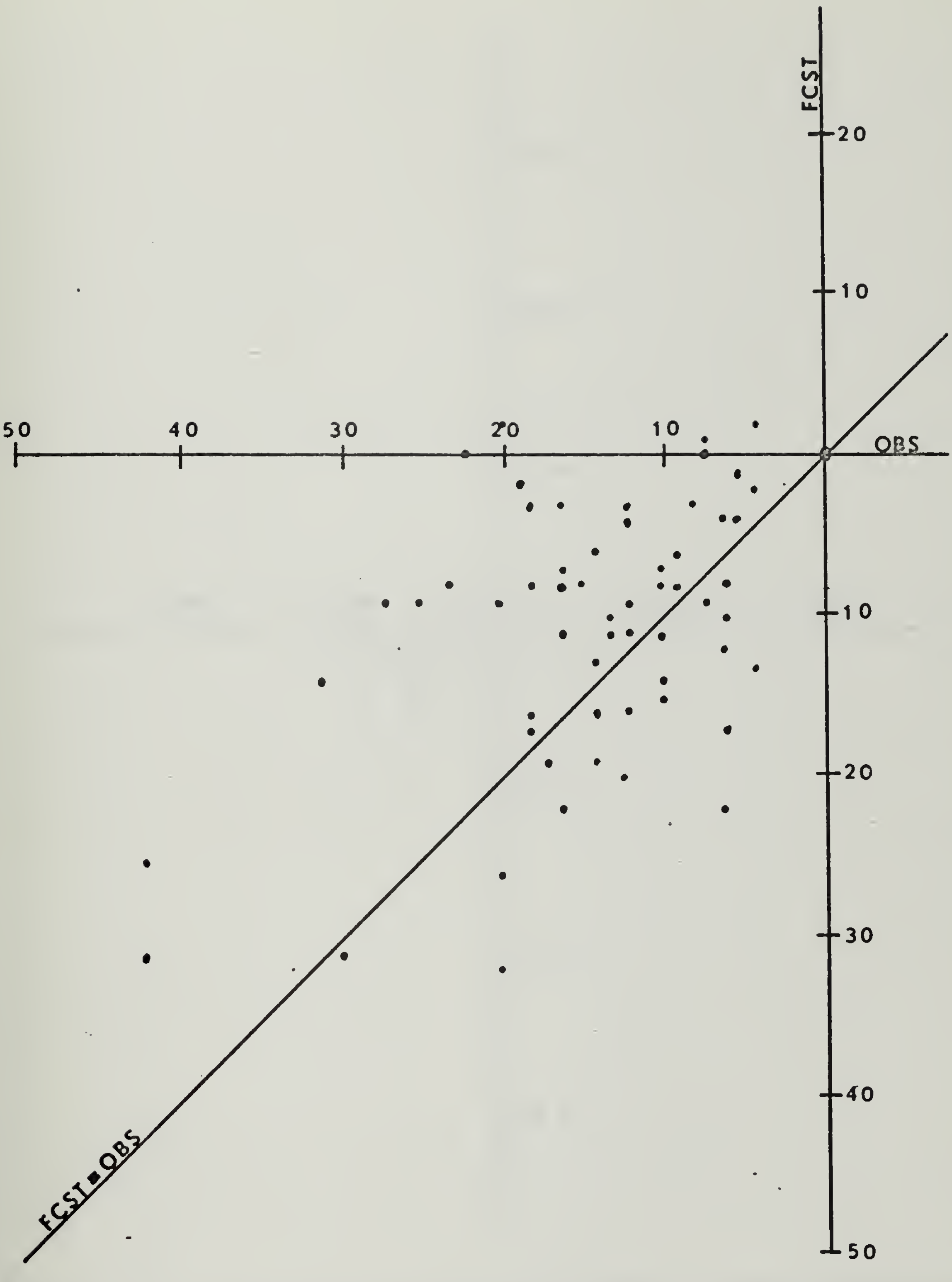


Figure 15. Cyclogenesis Area 4 (60W-40E) - Time interval 0-36 hours. Forecast versus observed deepening rate in mb.

Figure 16. Cyclogenesis Area 1 (105E-180) - 36-hour position error in degrees latitude and longitude.

Figure 17. Cyclogenesis Area 2 (180-110E) - 36-hour position error in degrees latitude and longitude.

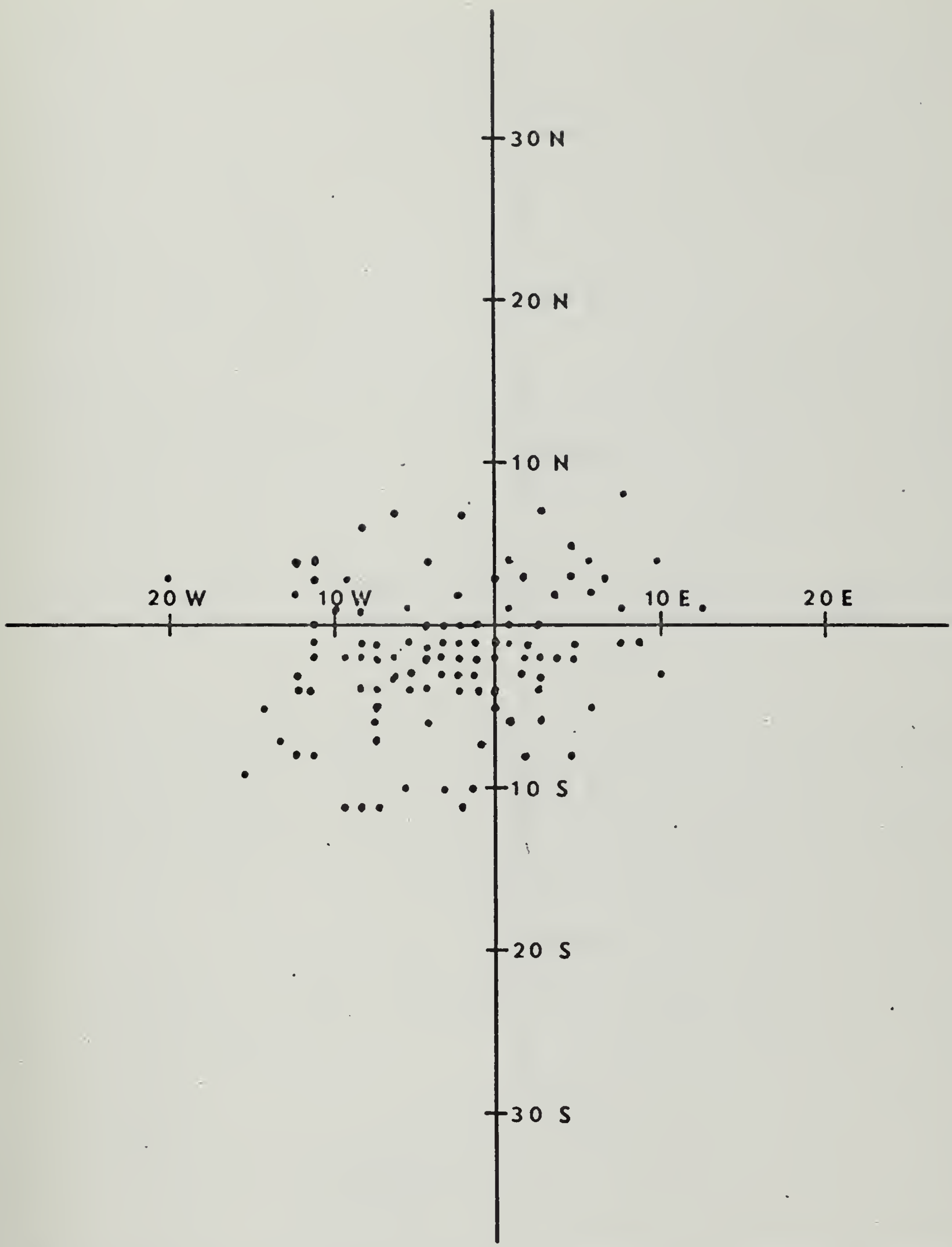


Figure 18. Cyclogenesis Area 3 (110W-60W) - 36-hour position error in degrees latitude and longitude.

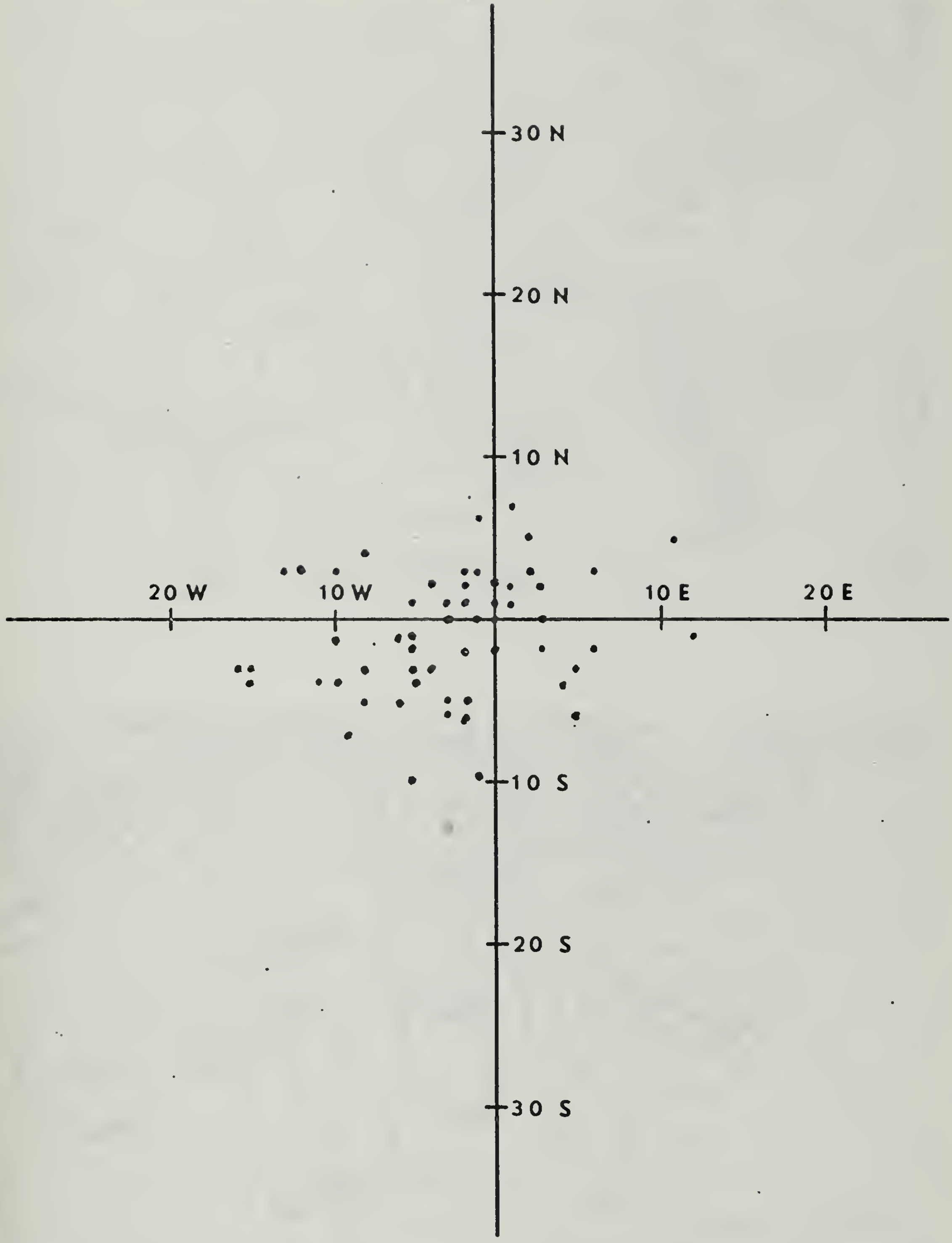
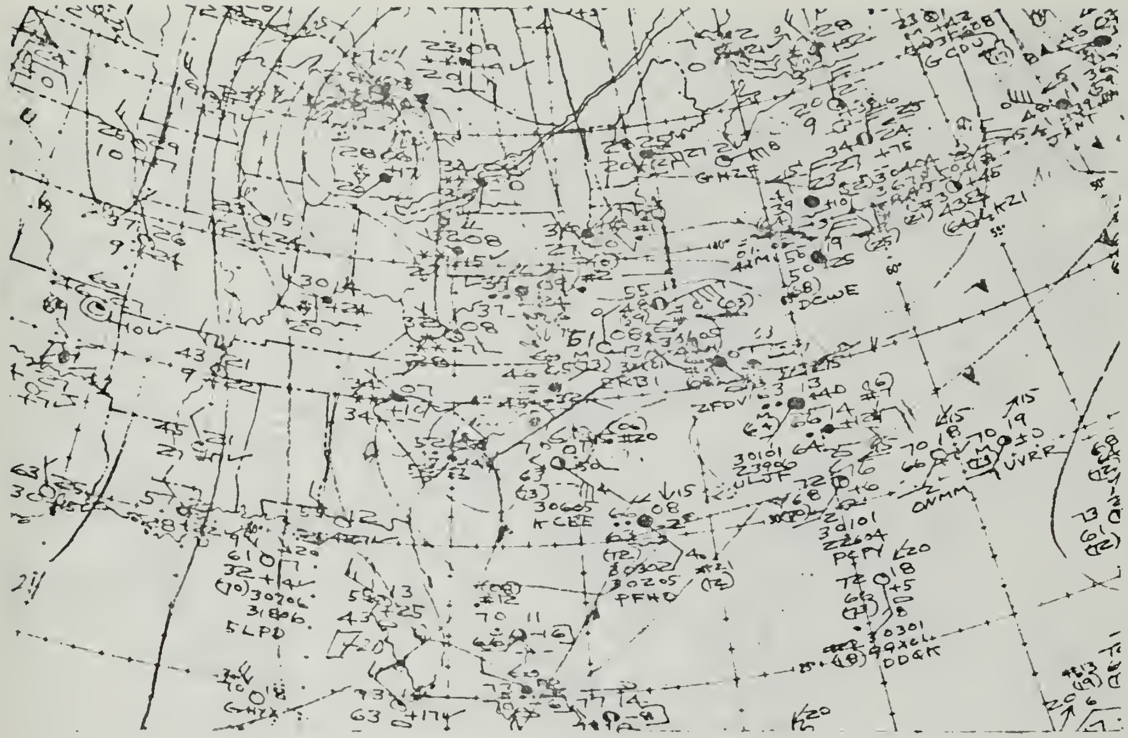


Figure 19. Cyclogenesis Area 4 (60W-40E) - 36-hour position error in degrees latitude and longitude.



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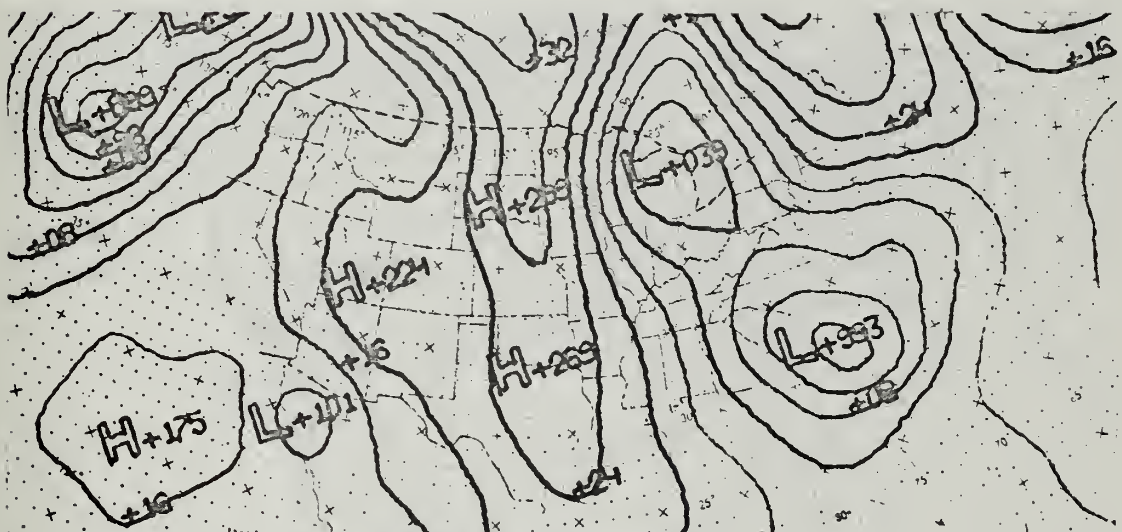

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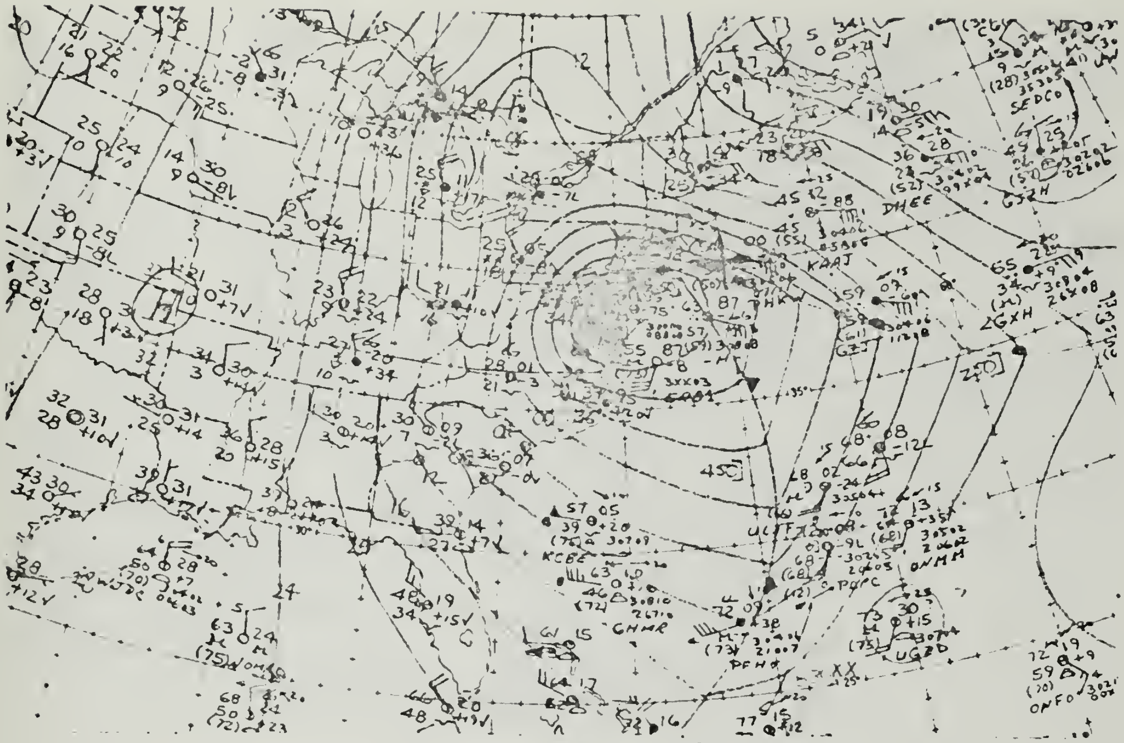
Figure 20. A. NMC Analysis; B. FNWC Analysis 0000 GMT 19 FEB 72



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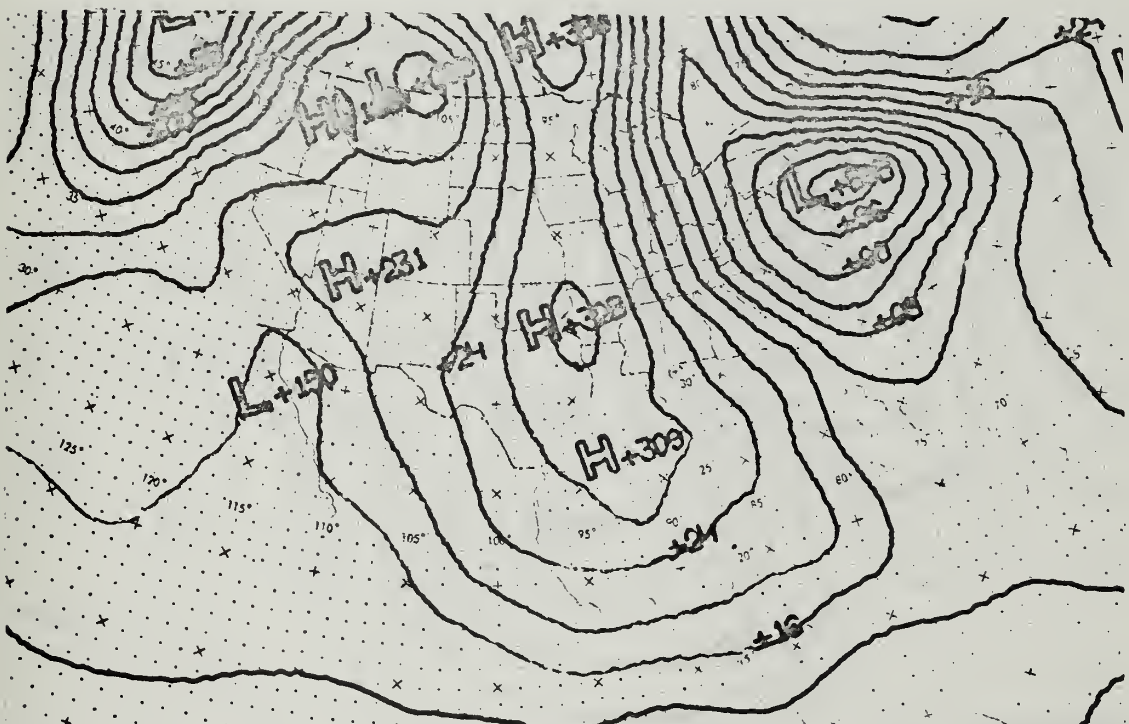

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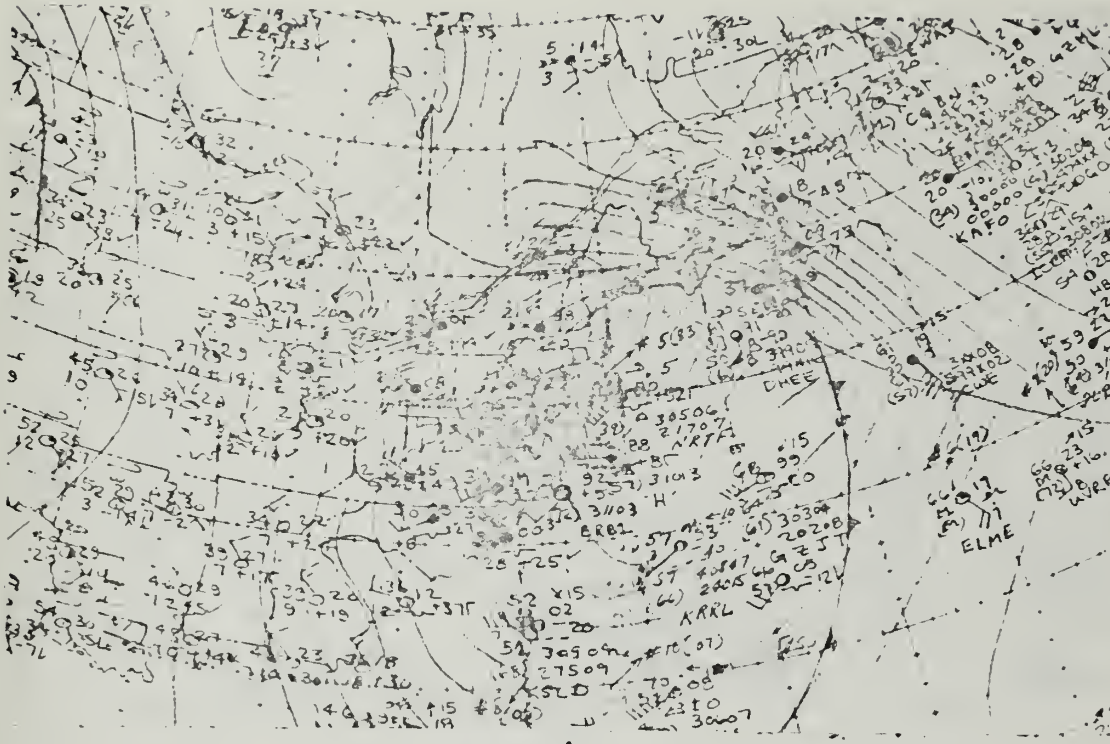
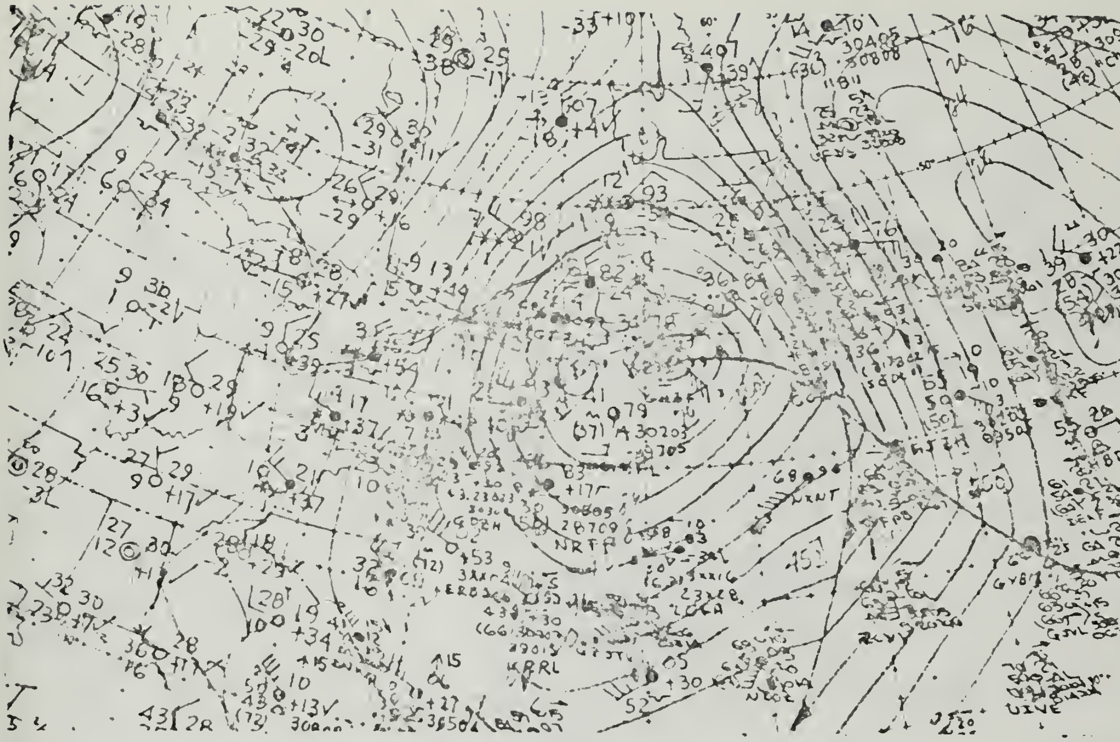
Figure 21. A. NMC Analysis; B. FNWC 12-hr. Forecast 1200 GMT 19 FEB 72



A

B

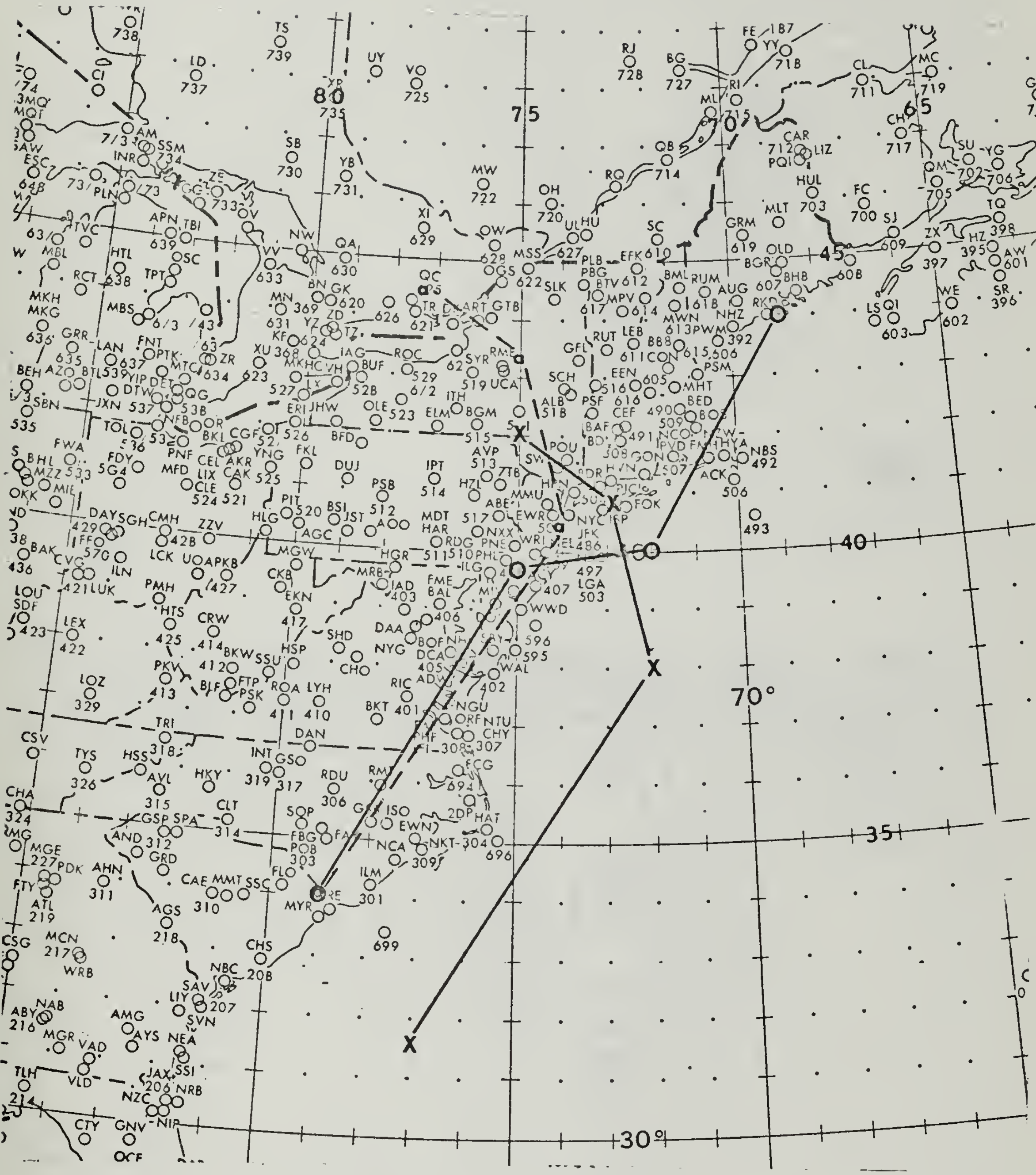
Figure 22. A. NMC Analysis; B. FNWC 24-hr. Forecast 0000 GMT 20 FEB 72



A

B

Figure 23. A. NMC Analysis; B. FNWC 36-hr. Forecast 1200GMT 20 FEB 72

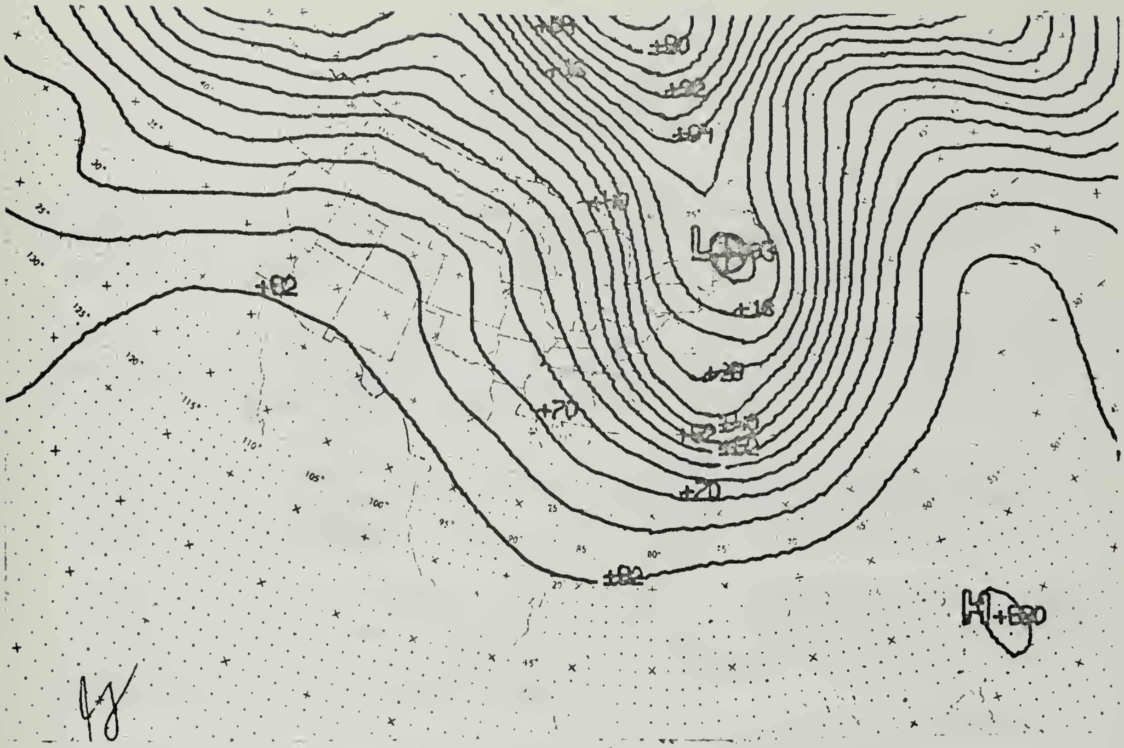


O: observed track

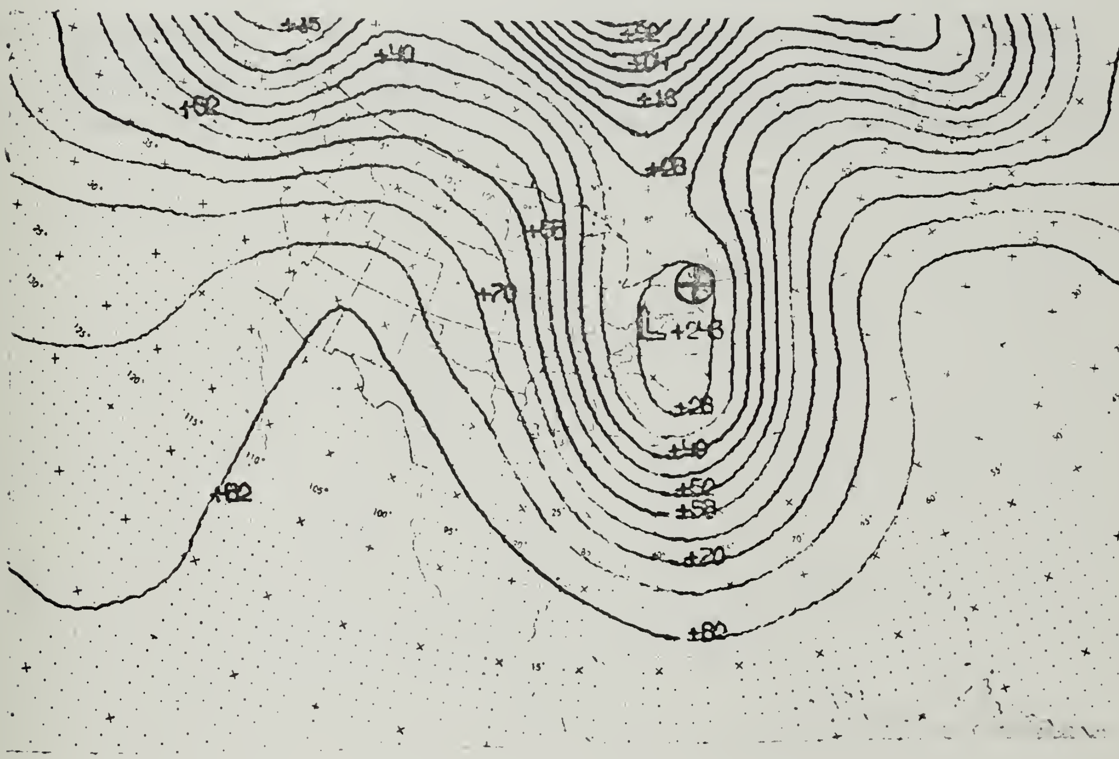
X: forecast track

a: adjusted track

Figure 24. Adjusted track comparison.



A.



B.

Figure 25. A. FNWC analyzed 500-mb heights, position of sea-level low center ⊕; B. FNWC 36-hour forecast 500-mb heights, position of sea-level low center ⊕.

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ORIGINATING ACTIVITY (*Corporate author*) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

REPORT TITLE

Evaluation of the Fleet Numerical Weather Central Operational Primitive-Equation Model in Forecasting Extratropical Cyclogenesis

DESCRIPTIVE NOTES (*Type of report and, inclusive dates*)

Master's Thesis; March 1973

AUTHOR(S) (*First name, middle initial, last name*)

Timothy D. Klopfenstein

REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1973	78	6

CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
PROJECT NO.	9b. OTHER REPORT NO(S) (*Any other numbers that may be assigned this report*)

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ABSTRACT

This paper describes an attempt to find systematic errors in the 12, 24 and 36-hour sea-level pressure forecasts of extratropical cyclogenesis produced by the operational five-layer primitive-equation model of the Fleet Numerical Weather Central, Monterey, California. The sample of cases studied contained 488 cases for the 12-hour, 484 cases for the 24-hour, and 446 cases for the 36-hour verifying times. The sample was extracted from the storm season spanning the period October 1971 through March 1972. Several systematic errors exist. They are: 1) an underforecast of the deepening rate in a majority of cases; 2) a tendency to greatly underforecast the deepening rate in the 12-hour prognoses and then to underforecast to a lesser degree or overforecast the subsequent 12-hour changes; 3) a tendency to forecast the track to the right of the actual track; and 4) a tendency to forecast the 36-hour position to the south and west of actual position. When compared to the National Meteorological Center's six-layer primitive-equation model, Fleet Numerical Weather Central's model showed comparable or superior performance.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT

DD FORM 1 NOV 65 1473 (BACK)
S/N 0101-807-6821

Thesis 143276
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